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CONCENTRATION AND CIRCULATION OF THE ELEMENTS FROM THE STANDPOINT OF ECONOMIC GEOLOGY.[1]

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NATURALLY the economic geologist is interested in the deposits of useful minerals. He examines their character and composition, the succession of minerals, the changes which take place in them, and he generalizes from his pains-taking researches as to the origin of these concentrations of elements, often such as are otherwise very sparsely disseminated in rocks of the earth. His conclusion is that while certain geologic processes effect concentration, others may result in renewed dissipation or scattering of slowly gathering aggregates.

If our economic geologist is of an inquisitive mind he may try to trace the laws of such migrations, or, if they are repeated, such cycles of travel. Probably he will find some elements which appear to enjoy these travels, while others will stubbornly refuse to move about extensively. The subject is fascinating indeed, though beset with difficulties owing to our fragmentary knowledge of the complex reactions.

Even at the risk of being considered as mid-Victorian in my views, I shall start with the assumption of a gaseous globe slowl consolidating to a condition of polyphase systems, and always governed by gravity.

[1] Presidential address read at the Ann Arbor Meeting of the Society of Economic Geologists, December, 1922.

In common with many other geologists I believe the earth to be composed of shells of substances gradually increasing in gravity. Goldschmidt,[2] for instance, assumes a thin crust, 120 kilometers thick, of silicate rocks of average specific gravity of 2.80 gradually changing to material of more basic composition; this is underlain by a shell of eclogite in which the densest minerals prevail like pyrope and pyroxene, stable under conditions of greatest pressure. Below this at a depth of almost 1,100 kilometers is a thicker shell of oxides and sulphides with a specific gravity of from 5 to 6. This is assumed to be about 1,600 kilometers deep, and is followed by a central mass mainly of nickel-iron and having a specific gravity of about 8, the thickness of which would amount to a little more than one-half of the total length of the radius or 6,450 kilometers. We may not necessarily accept this subdivision in detail. Concerning the shell of eclogite there may be grave doubt as to whether crystallinity can really exist at a depth of 1,200 to 2,900 kilometers.

H. S. Washington[3] basing his views, as does Goldschmidt, on the data gathered by physicists, astronomers and seismologists expresses similar views and holds moreover that the central core, below the nickel iron zone, is composed of elements of highest atomic weight either as metals or possibly in the form of selenides, tellurides, or arsenides. A core of platinum or gold is certainly an interesting possibility. In confirmation of this belief he cites C. J. Abbot's conclusion as to the distribution of the elements in the sun, the elements of low atomic weight showing the most intense spectrum lines, and consequently being most abundant at the surface of the sun.

Washington further points out the difference between the "petrogenic" elements or those that make up the bulk of the rocks, and the "metallogenetic" elements or "ore elements" which includes those of economic and industrial importance. The former occur

[2] V. M. Goldschmidt, "Der Stoffwechsel der Erde." Paper read at the Centennial of the "Gesellschaft Deutscher Naturforscher und Aerzte." Leipzig, 1922.

[3] H. S. Washington, "The Chemistry of the Earth's Crust," *Journal of the Franklin Institute*, vol. 190, pp. 757–815, Dec., 1920.

mainly as silicates, oxides, fluorides, and chlorides; the latter as sulphides, arsenides, selenides, or tellurides. While there are some exceptions, like iron and tin, the distinction seems to be valid. Washington further discusses the peculiar position of these two great groups in the periodic system and the scarcity of the latter in the crust, compared to the abundance of the former. As gravity is the controlling factor in the distribution of the elements it follows that the bulk of cultural metals are practically beyond our reach.

Goldschmidt suggests that the fluid globe may be regarded as a three phase system of three practically immiscible components. (1) Silicate melt; (2) Sulphide melt; and (3) Metals, corresponding to slag, matte and metal in metallurgical practice.

Clarke and Washington [4] have recently recalculated the composition of the crust, which is assumed to be the outer rock shell of the earth 16 kilometers deep and having a specific gravity of 2.77. The elemental composition based on 5,159 analyses from all parts of the earth follows. An estimate is also appended of the percentage of rare metals.

These tables show that practically every element is contained in the crust, but that the scarcest elements are those of high atomic weight. In the first table only barium, cerium, and lead have atomic weights above 100, and in the second table only arsenic, molybdenum, bromine, scandium, selenium, gallium, and germanium have atomic weights below 100.

It hardly needs to be emphasized that rocks of the crust of the earth, though containing practically all elements, are generally worthless for the purpose of extracting cultural metals. Almost all metalliferous deposits are exceptional concentrations which are not considered in the computation. Even if they had been considered and weighted they would scarcely have altered the average composition. The composition of the crust of the earth, therefore, throws little direct light on the origin of mineral deposits and the circulation of the elements.

[4] F. W. Clarke and H. S. Washington, "The Average Chemical Composition of Igneous Rocks," *Proc. Nat. Acad. Sci.*, March 22, 1922.

Average Composition Ten Mile Crust Igneous Rocks.		Rarer Elements in Igneous Rocks (Estimate).	
Oxygen	46.41	Rubidium	0.000X %
Silicon	27.58	Arsenic	
Aluminum	8.08	Molybdenum	
Iron	5.08	Tin	
Calcium	3.61	Bromine	
Sodium	2.83		
Potassium	2.58	Cæsium	0.000,0X %
Magnesium	2.09	Scandium	
Titanium	0.720	Antimony	
Phosphorus	0.157	Cadmium	
Hydrogen	0.129	Mercury	
Manganese	0.124	Iodine	
Chlorine	0.096		
Barium	0.081	Bismuth	0.000,00X %
Sulphur	0.080	Tungsten	
Chromium	0.068	Thorium	
Zirconium	0.052	Columbium and Tantalum	
Carbon	0.051	Uranium	
Vanadium	0.041	Silver	
Strontium	0.034	Selenium	
Nickel	0.031		
Fluorine	0.030	Platinum	0.000,000,X %
Cerium Metals	0.020	Tellurium	
Copper	0.010	Gold	
Zinc	0.004		
Lead	0.002	Thallium—0.000,000,0X %	
Cobalt	0.003		
Lithium	0.005	Indium	0.000,000,00X %
Boron	0.001	Gallium	
Beryllium	0.001		
	100.000	Germanium—0.000,000,000,X %	
		Radium—0.000,000,000,00X %	

Owing to local conditions, for instance, release of pressure, the predominantly solid crust may become fused and intrusions and effusions follow, preceded by differentiation of the magmas. It is generally accepted among petrologists that the dominating factor in differentiation is fractional crystallization. Under the influence of gravity a separation will be effected, the heavier minerals sinking to the bottom. Thus, not only will different kinds of silicate rocks result, but, also, mineral deposits of oxides and sulphides. Principally these will be derived from the basic rocks.

Concentrations result of magnetite, ilmenite, pyrrhotite, and other sulphides, which according to metallurgical experience will carry with them the bulk of the nickel, cobalt, copper, gold and silver, and the platinum metals of the magma. In places phosphorus will join the procession of the heavy metals, and the tendency of these minerals will be to sink, thus in general removing them from the surface vicinity. This accounts probably for the scarcity of sulphide deposits like those of Sudbury or of magnetite deposits like that of Kiruna.

Fortunately for humanity there is, however, another factor accompanying the differentiation of the magmas, which works in the opposite direction. The lighter constituents like silica and the feldspars tend to ascend and with them gaseous components. All metals which have an affiliation with the acidic constituents and those which form liquid or gaseous compounds with the halogens will be carried along towards the surface, that is towards the accessible region.

These lighter and volatile accumulations of the magma may be divided in (1) The salic extracts, mostly represented in pegmatite dikes; and (2) The gas fluxing components, which appear as volcanic gases and sublimates near the surface or as veins and replacement deposits in depth. In both cases silica is the principal carrier entraining with it large masses of volatile and soluble matter. There is no sharp division between the two classes.

The salic extracts form the lighter, upper part of intrusions or are squeezed out from these and typically contain much silica with alumina, and alkalies. Many rarer elements are present as silicates, phosphates, columbates, and tantalates, oxides, native metals, or rarely arsenides, and still more rarely sulphides. There is more or less fluorine and boron. The pegmatites of subalkaline rocks contain tin, molybdenum, tungsten, beryllium, cerium metals, thorium, lithium, uranium and radium.

The pegmatites of alkaline rocks carry predominantly sodium, often chlorine, and usually much zirconium and titanium. The rarer basic pegmatites contain apatite, molybdenite and pyrrhotite, also, many titanium minerals.

It need not be emphasized that the pegmatite dikes are the store-houses for the rare earth minerals, rutile, the columbates, many gems and the generally useful minerals of feldspar, quartz, and mica.

The salic extracts are the first and last deposits for many minerals. Except for local concentration in sediments by reason of gravity and indestructibility most of the rare elements disappear from our knowledge after decomposition and erosion have done their work. Tin, tungsten thorium, columbium, cerium, beryllium, and zirconium are apparently not reconcentrated by any geological agencies as far as we know. Uranium alone appears again in sedimentation and in biological cycles. Lithium may be dissolved and carried by meteoric waters.

The persilicic waters from the magmas ascend towards the surface laden with the gas fluxing products, and form a great variety of ore deposits. They carry carbon dioxide, hydrogen sulphide, fluorides, chlorides, phosphate, sulphates, metallic sulphides, arsenides, selenides, and tellurides. The metals are gold, silver, iron, copper, lead, zinc, bismuth, molybdenum, tungsten, tin, mercury, manganese, nickel, cobalt, uranium, and radium, and many others. They do not usually carry the rare earths, and compounds of titanium and zirconium, or beryllium. These deposits are the store-houses from which we draw the majority of our cultural metals, excepting iron and manganese. When the great dissipating agencies of weathering and erosion begin their work on the deposits they may momentarily enrich them and concentrate them but soon many of these elements disappear and we know them no more. That applies to antimony, bismuth, tungsten, tin, and mercury. Where do they go? Probably to infinitesimal subdivision in sea water and sediments. Some of them we can trace. Silver and gold go into the sea water; very little of them in the sediments. Arsenic, with vanadium and sulphur and phosphorus tend to be precipitated with the hydroxide of iron. Copper, lead, and zinc are recognized in the sediments, but after all do not these metals, as well as the gold and silver in the same sediments come rather from the original igneous rocks than from ore deposits? Locally they may come from such concentrations.

To a large extent then the gas fluxing products remain fixed in the upper crust, but during surface eruptions vast quantities also escape in the atmosphere, particularly water, nitrogen, carbon dioxide, sulphur dioxide, chlorides, and many other substances, and of these a large proportion return to the surface or to the sea. The fate of the many sublimates, which accompany eruption is commonly also to be merged in the sea. There are, also, continuous effluvia not necessarily of volcanic origin like some carbon dioxide, carbon monoxide, methane, nitrogen, and ammonia. Helium thrown off by radium ascends to mingle with the hydrogen of the upper gas shell of the earth.

The fourth process which we have to consider as effecting concentration and dissipation is the solvent power of underground waters of meteoric origin.

Descending as rain meteoric waters decompose and dissolve the rocks. The scant chlorine is extracted, sulphides are oxidized to sulphates, alkalies, and alkaline earths are converted to carbonates, silica, and a little alumina dissolved. Ultimately there will be much water fixed in hydration but were there no other considerations the result would be a continuous abstraction of constituents of the rocks during the descent of the waters into the crust, and when the waters after their round trip reappear at the surface the solution would largely be carried to sea. Actually the amount abstracted from the crust is smaller than we would expect for the concentrated solutions tend to fill cavities and pores with carbonates and silica.

Of still greater importance is the exchange of materials which we know as metasomatism. The underground waters affect complicated transformations in all rocks, the volume being constant. Thus chlorite and serpentine are substituted for anhydrous ferromagnesium silicates; sericite, and zoisite for feldspars. It is not possible to draw up a balance sheet for these transactions but the sum total is that the water carries down salts from the zone of weathering for the metasomatosis of the deeper rocks, and large quantities of the components of the latter are in exchange carried to the surface. Many non-metallic deposits, as of talc, serpentine,

and sulphur, may be formed this way. And when the waters traverse easily leached rocks like limestones and sandstones, metallic deposits of copper, lead, zinc, and even vanadium and uranium may result.

In great depth and under stress the meteoric waters move slowly. Changes take long time, and are not so radical. The composition tends to conform with that of the most abundant mineral.

The fifth process to be considered is that carried on by the surface waters under oxidizing conditions. For the transportation of elements—concentration and dissipation—this is of the greatest importance. Decay attacks the crust by radical and rock-destroying methods. Leaching on a large scale is the rule, the run-off discharging soluble carbonates, sulphates, and chlorides—also silica and some alumina into the sea, more or less of practically all of the rare elements in the rocks. This is dissipation on a large scale and a process of paramount importance for the composition of the sea water and the support of the whole array of marine life.

The residue or mixtures of unaltered grains and colloids is, in part, transported to the sea as suspended sediments; a separation takes place and there results beds of silica sands, beds of more or less pure colloidal and detrital clays. In the clays, titanium and some vanadium tends to concentrate.

Another part of the residue remains in place and is composed chiefly of kaolin, quartz, limonite and manganese dioxide, and in this clayey, colloidal mass manifold concentrations take place, usually resulting in nodular and concretionary structures. I refer, for instance, to deposits of barite, phosphates, psilomelane, limonite, other residual ores, and to the bauxite, the hydroxide of aluminum, practically our only ore for that metal, and formed under tropical suns from kaolin and colloids of aluminum silicate. Hematite forms under similar conditions instead of limonite from iron-bearing igneous and sedimentary rocks. Finally erosion carries away the last residues of rock decay and the cycle is closed, the stage set for another scene.

The fifth process, also, makes possible vegetable life supported by the thin crust of soil on the decaying rocks with its complex cycles of lime, iron, silica, nitrogen, sulphur, phosphorus, iodine, sodium and potassium. The vegetation gives up these constituents to the plant-eating animals, and the bodies of the latter feed the carnivoræ.

The sixth process involved with the preceding one is that of sedimentation, fluviatile and marine. Sedimentation works by gravity, by chemical and by biochemical processes.

The conglomerates, sandstones, silts and clays are mainly detrital while the limestones are largely the product of biochemical activity. The main part of the sediments consists of clayey products. Altogether they form but a thin veneer, a few per cent. of the 16 kilometer crust of the earth. But for our life they are of tremendous importance for during this sorting process chemical and biochemical reactions take place which result in our largest deposits of iron, manganese, phosphates, calcium carbonate, gypsum, and alkaline chlorides. The sediments are raised and folded again attacked by rock decay and re-deposited in successive cycles. Rock decay and sedimentation, both operating in the thin surface shell, tend strongly to produce extreme separation of individual components. They are also characterized by the most pronounced dissipation of elements.

For tracing the chemical changes which take place during the transformation of igneous rocks to sediments the fine silts and muds are particularly interesting for they form about 95 per cent. of the sediment veneer of the crust.

For this purpose I have arranged side by side the average percentage composition of all igneous rocks, of the silts of Mississippi delta and of blue and green " terrigenous " marine muds.

The analyses given above carry considerable weight, for each column is a composite of a large number of samples. It may be of interest to compare them in detail. After the cooling of the igneous rocks comes decomposition, weathering, erosion, and sedimentation, all processes involving a great amount of solution and mechanical transportation. Of the original rock the larger part

COMPARATIVE RESULTS OF SEDIMENTATION.

	1.	2.	3.
SiO_2	59.12	69.96	57.05
Al_2O_3	15.34	10.52	17.22
Fe_2O_3	3.08	3.47	5.07
FeO	3.80		2.30
MgO	3.49	1.41	2.17
CaO	5.08	2.17	2.04
Na_2O	3.84	1.51	1.05
K_2O	3.13	2.30	2.25
H_2O	1.15	3.78 − 1.96 +	7.17
CO_2	0.101	1.40	.....
TiO_2	1.050	0.59	1.27
ZrO_2	0.039	0.05	.....
P_2O_5	0.299	0.18	0.21
Cl	0.048	0.30	.....
F	0.030	0.07	.....
S	0.052	0.07	0.13
SO_3	.....	0.03	.....
$(Ce,Y)_2O_3$	0.020	.....	.....
Cr_2O_3	0.055	0.01	0.05
V_2O_3	0.026	0.02	0.03
MnO	0.124	0.06	0.12
NiO	0.025	0.017	0.063
BaO	0.055	0.08	0.06
SrO	0.022	tr	0.03
Li_2O	0.008	.....	.....
Cu	0.010	0.0033	0.0120
Zn	0.004	0.0008	0.0053
Pb	0.002	0.0002	0.0004
As_2O_5	.....	0.0004	trace
Organic Matter	.....	0.66	.....
Carbon	.....	.....	1.69
Totals	100.000	100.6217	99.9907

1. Average composition of igneous rocks. Clarke and Washington, 1922.
2. Mississippi delta silts, 235 samples. Geo. Steiger, Analyst. Clarke, Geo-chemistry, 1920, p. 501.
3. Marine terrigenous clays, 52 samples. Geo. Steiger, Analyst. Clarke, Geochemistry, 1920, p. 510.

remains in analyses 2 and 3. All of the original constituents have of course been more or less leached and removed but without much more information we are unable to say to what percentage. The relative amount of removal is indicated however. The following table shows the apparent gains and losses in comparing first 1 and 2, then 1 and 3.

APPARENT GAINS AND LOSSES.

	A 1 to 2.	B 1 to 3.
SiO_2	+10.84	—2.07
Al_2O_3	— 4.82	+1.88
$Fe_2O_3 + FeO$	— 3.41	+0.49
MgO	— 2.02	—1.32
CaO	— 2.91	—3.04
Na_2O	— 2.33	—2.79
K_2O	— 0.83	—0.88
$H_2O +$	+ 0.81	+6.02
CO_2	+ 1.299	
TiO_2	— 0.460	+0.22
ZrO_2	+ 0.011	
P_2O_5	— 0.119	—0.089
Cl	+ 0.252	
F	+ 0.840	
S	+ 0.018*	+0.088
Cr_2O_3	— 0.045	—0.005
V_2O_3	— 0.006	+0.004
MnO	— 0.064	—0.004
NiO	— 0.008	+0.038
BaO	+ 0.025	+0.008
SrO		+0.008
Cu	— 0.0067	+0.002
Zn	— 0.0031	+0.0013
Pb	— 0.0018	—0.0016
Organic matter	+ 0.66	

* + 0.03 SO_3.

The most striking gain in comparing 1 and 2 is in silica and represents mainly mechanical concentration of quartz. Zirconium probably accompanies the quartz as inclusions. Quite decided are the gains in chlorine, fluorine, and sulphur, suggesting that if by some chance such sediments were assimilated by magmas they would not be lacking in mineralizers. The gain in barium is interesting and scarcely suspected; the apparent losses in vanadium and nickel are small.

Among the losses all the common rock-forming bases are conspicuous. We note a relative loss of magnesia and lime both to the extent of 57 per cent. of the amounts in the original rock. Soda loses 61 per cent. or more than any other of these constitu-

ents; potash shows a loss of only 27 per cent. Losses prevail among most of the rarer metals, but, of course, their expression in percentages would not mean much.

The comparison between 1 and 3 brings out the gain in alumina and water, which, of course, was to be expected, but there is, also, a very decided gain in iron oxides, in titanium and in sulphur (fluorine and chlorine not determined); the titanium follows the alumina. Chromium is almost constant, quite certainly there is an apparent increase in vanadium, nickel, barium, strontium, copper, and zinc, while lead diminishes. These facts are of considerable interest in connection with the biologic processes referred to later. Magnesia, lime, and alkalies show losses similar to those in the silts, potash being lost to a considerable smaller amount than soda.

It may be argued that these analyses do not represent the direct change from igneous rocks to silt and clay for the material represented in columns 2 and 3 is undoubtedly largely derived from sedimentary rocks. I do not think that this lessens their value for comparison; it simply emphasizes more the changes by successive sedimentary cycles. That these comparisons in many instances are not far from indicating the actual gains and losses would appear from the calculations made by Leith and Mead.[5] These investigators point out quite correctly that during sedimentation considerable gains are made of water, carbon dioxide oxygen and other constituents derived from the atmosphere and the hydrosphere. Their main result is that 100 grams of igneous rock yield 114 grams of end products consisting approximately of 87.8 grams of shale, 12.9 grams of sandstone, 6.7 grams of limestone and 6.6 grams of ocean salts.

Total weight of sediments derived from 100 grams of igneous rock is therefore 107.4 grams.

Expressing it in another way, 100 grams of igneous rocks contribute approximately 97 grams to the sediments, the remaining 3 grams going to the salts of the sea.

[5] C. K. Leith and W. J. Mead, "Metamorphic Geology," New York, 1915, pp. 64 and 69.

Biochemical Processes.—Plants and animals play an intense and dramatic part in the concentration of certain elements, but we do not by any means know all the details of this wonderful story. Chemical physiology is our source of information, and this branch of science has not always followed closely the wanderings of elements in which we are interested. Biochemical processes involve the concentration of certain elements. They, also, involve a certain amount of dissipation during life. After the death of the being, dissipation is the rule unless counteracted by certain other processes. The living matter collects elements, which it needs; after death it gives them up to the media by which they live and have their being.

Often we observe consecutive stages in concentration. In the sea water the blue-green algæ concentrate phosphorus, certain mollusks or crustaceans feed on the algæ, and other meat eating mollusks devour the vegetarians. Small fishes eat the mollusks, large fishes eat the small, finally seals and birds swallow the fishes, and so in about six transformations the phosphorus originally contained in the sea-water may come to rest in deposits of guano on desert islands or in accumulations of bones of vertebrate denizens of the sea.

Were our knowledge more exhaustive we could compile similar history of wanderings for many of the elements. Phosphorus [5a] has been followed in detail because it is almost the most essential mineral constituent of life. From the phosphates disseminated in rocks as apatite or accumulated by gravitation or gas fluxing processes in iron ores, pegmatites and veins, this element is to a large extent dissipated by weathering of the rocks as complex calcium, iron, and alkaline phosphate solutions, which eventually find their way to sea. Part of the element goes through the elaborate cycle outlined above; other parts enter new sediments as complex fluocarbono-phosphates, its solution being prevented in one way or another. The sediments become dry land, are folded and uplifted, surface waters begin their part of concentration by weathering to deposits of economic importance, finally the sediments

[5a] Eliot Blackwelder, "The Geologic Rôle of Phosphorus," *Am. Jour. Sci.*, 4th ser., Vol. 42, 1916, pp. 285–298.

waste away and the phosphorus is dissipated. Or again, though less commonly, the sediments may become absorbed in magmas and the phosphorus returns to its original condition of apatite. The amount of phosphates in circulation to support life must be enormous, but who is able to draw up a balance sheet for these astounding transactions?

Plants are continually accumulating carbon from the atmosphere. The carbon is returned by decay, or under protective cover is indefinitely preserved until the coal seams, exposed to the air slowly oxidize or struck by lightning burn to a red band along the hillside, or again man steps in and by combustion returns vast amounts to the atmosphere. Plants also accumulate potash, phosphorus, nitrogen, silica, and calcium carbonates; their chlorophyll demands iron and magnesium. But most of these things are returned to the atmosphere or to the soil solution after death. However, the calcium carbonate of algæ, the silica of diatoms may accumulate to important deposits. The ashes of plants give us a clue to many of these complex processes. Take sea-weed for instance: In its ashes have been found potassium, iodine, nickel, cobalt, barium, and strontium, and even copper, zinc, and boron; in this case the concentration of iodine has had a certain economic importance. Whence came the iodine, whence the boron? Undoubtedly set free by gas fluxing operations in magmas, thence discharged into the sea.

Copper, lead, and zinc, also nickel and cobalt have been found in ashes of coal, but it is possible that these elements came indirectly by precipitation as sulphides along with marcasite from sulphate solutions—these again derived from the oxidation of older iron sulphides of sedimentary rocks. Molybdenum is reported in one case, frequently vanadium and uranium. There is too little of definite information along these lines. I suspect molybdenum as well as chromium of some rôle in the organic cycle, and I am sure such a part is played by vanadium and uranium, but this will be referred to furthur on.

Even the lowest forms of vegetable life are of importance for the concentration of some deposits. Think of the iron and manganese bacteria which no doubt are essential for the formation of

certain bog ore deposits—consider the sulphur bacteria that according to some authors have actively contributed to some sulphur deposits.

No less important is the part played by animals, particularly those of the sea. For the animals that roam over the earth are likely to return their bodies to the air and the soil, while in the sea the more or less continuous sedimentation may cover and preserve their remains. Take the case of barium and strontium, originally contained in igneous rocks—quite abundantly in some alkaline varieties—and undoubtedly in part given off by igneous emanation. The solutions from the land carry a continuous stream of these elements into the sea. Their presence in the seawater is well established. It has been shown above that barium and strontium are actually present in silts and muds in larger amounts than in igneous rocks. In agreement with this, most of our deposits of sulphates and carbonates of these metals are found in sedimentary rocks; such circumstances indicating concentration by later searching meteoric waters. Are there any organic agencies which may effect a slight concentration in the sediments of the barium found in the sea? The biologists answer this by telling us that certain protozoans segregate barium sulphate in minute crystals in their tissues and that certain radiolaria like Acantharia form their skeletons, in part, of strontium sulphate. Is there not a source here for meteoric waters to work upon when millions of their bodies were covered by rapid sedimentation?

The substances which are concentrated by the inhabitants of the sea include silica, sulphur, and potassium, the carbonates of calcium and magnesium and the carbono-phosphates of calcium. These produce directly or indirectly such deposits as phosphate beds and glauconite sands and limestones. We observe also the accumulation of heavy metals, such as copper, lead, zinc, and vanadium, and apparently also cobalt, nickel, and manganese. The three last named metals have been determined in analysis of globigerina ooze, and they are probably of organic origin.

In the blood of molluscs[6] copper appears as an important con-

[6] Molluscs, crustaceans, many insects (*e.g., Blatta orientalis*) and fishes con-

stituent, also zinc, and probably lead. Zinc, copper, nickel, and cobalt certainly occur in sea water, and their biochemical concentration becomes one of the important marine processes.

Crustaceans are rich in zinc. Lead is more doubtful but the observations of Van Ingen makes it pretty sure that in some form or other this element is contained in the molluscs. Vanadium takes the place of copper in the blood of ascidians, and holothurians;[7] to what extent by other animals is, as yet, not ascertained. Anyway, vanadium must be an important constituent of sea-water, though I can find no analysis confirming this. The whole subject is imperfectly known.

Collectively and quantitatively these concentrations of heavy metals in sea animals is enormous. Naturally much of the metal is returned to the sea when the animal dies, but if for some reason or other the death rate is high, and the remains buried in sediments much of the metals must be retained in the mud; most probably in the state of sulphides. Indeed, as Professor Van Ingen has shown minute particles of sulphides, mostly zincblende or galena is often found in fossilized molluscs, which have been preserved by such a process of burial. The copper, lead, and zinc came originally from the decomposition and decay of igneous rocks in which they are always present, possibly also from the disintegration of sediments, which likewise contain them, or from the outcrops of deposits which themselves obtained the metals from gas-fluxing processes.

The Story of Iron.—Let us follow for a moment the wanderings of iron, that most useful of cultural metals. Unlike the others it is common and abundant, yet the igneous rocks of which

tain copper to the amount of from 1 to 14 milligrams per 100 grams of living animal. Zinc, a characteristic constituent of the human liver, is present in gasteropods; often there is more zinc than copper. The ashes of meat gasteropods contain about 12 per cent. ZnO and 7.8 per cent. CuO. See Carl Oppenheim, "Handbuch der Biochemie," Berlin, vol. 1, 1909.

[7] A. H. Phillips found 0.123 per cent. of the weight of the entire animal dried at 110 deg. (Am. Jour. Sci. (4), vol. 46, 1918, p. 473). M. Henze found 18.5 per cent. V_2O_5 in the chromogen in the blood of ascidians. Some species of these animals do not appear to carry vanadium. (Z. f. Physiol. Chemie, 72, 1911, pp. 494–501.)

it forms a component averaging 6 per cent. in the combined oxides are of no use to us as a source of that metal. The amount varies very much indeed, the more basic rocks containing as much as 12 to 16 per cent. of FeO plus Fe_2O_3. The rocks form, however, much of the raw material for our ores and the metal is easily concentrated from them.

Iron oxides, particularly magnetite, sink in the magmas to form strongly ferriferous rocks, even massive magnetite, usually accompanied by the faithful companions titanium, phosphorus and vanadium. These differentiation products are sometimes brought to the surface as masses in the rocks or as dikes.

Magnetite is also, though rarely in quantities, brought up by the salic extracts, that is, in pegmatite dikes. Much more abundantly it is carried up as a gas fluxing product, probably in combination with halogens. Absorbed by limestones it takes the form of magnetite, pyrrhotite, and pyrite in contact metamorphic deposits. Carried up by the persilicic waters it is deposited as veins and replacement deposits as pyrite, pyrrhotite, and other sulphides or as arsenides. In all these forms it makes deposits of economic importance, the sulphides, and the apatite-magnetite mixtures being utilized only lately as metallurgical methods improved.

These " hypogene " deposits we may contrast with those formed by processes whose home is in or near the surface.

Meteoric waters circulating in the crust dissolve the iron of the rocks and when overloaded deposit it below as sulphides or carbonates—a process rarely of great economic importance. Surface waters oxidize all rocks in the zone of weathering and particularly in the basic rocks they find a suitable raw material for their concentrating action. Magnetite is washed down to beds of " black sand." All rocks are decomposed yielding soluble iron salts easily oxidized or hydrolyzed to the ultimate subaërial product, ferric hydroxides. A large part of the iron of the rocks remains thus in situ or carried a little ways may replace limestone. Colloidal processes are at work in the weathered rocks concentrating the scattered limonite to deposits of some importance. A smaller

part stays in solution as bicarbonates or sulphate, and is carried to the sea, there to give rise to new iron deposits.

The continuous stream of soluble iron salts which reach the shores from ferriferous regions of rock decay is largely precipitated by complex reactions in the sea water, in part biochemical, to silicates (glauconite, chamosite), to carbonate (siderite) and to hematite, the precipitate usually assuming oölitic texture. In the littoral muds rich in animal ooze there is often enough sulphur to cause abundant precipitation of colloidal iron sulphides, later crystallizing as pyrite or marcasite. In muddy waters rich in vegetable substance siderite may be precipitated, which later accompanies the coal seams as "black bands." Epochs of uplift subject the hardened sediments again to limonitic alteration and solution, and the products are again swept to the sea.

Besides these major cycles there are minor paths of circulation usually of biochemical nature. The plants need organic iron compounds, which they absorb from the soil, and after their death the iron returns to the soil, or land animals, man included, feed on plants absorbing their iron. Meat eating animals, including man, feed on the plant eating species, and obtain their iron from them or from the blood of other carnivorous beings. Similar cycles are in operation in the sea though for these marine inhabitants iron is less of a necessity than for those of the land. Essentially, the secondary iron deposits are products of the land, or the shores. There seems to be very little iron in the sea water, perhaps 0.00x per cent. in the dissolved salts. It seems to be very readily removed just like phosphorus.

The Story of Sulphur.—Sulphur like phosphorus has an absorbing story to tell. Clarke and Washington inform us that the average igneous rock has a content of 0.08 per cent. sulphur. There is considerable irregularity in its distribution, however; the basic rocks carry much more of it than the acidic types. Probably the figure given is really a little too high for even apparently fresh igneous rocks often contain pyrite of later introduction. In the differentiation of the magmas the sulphides tend to sink and these magmatic concentrations rich in sulphur rarely reach the surface.

The basic rocks, then, are one of the potential sources of sulphur deposits. Much more spectacular is the continuous stream of sulphur rising towards the surface by gas fluxing processes. All active volcanoes give off enormous quantities of hydrogen sulphide some oxidized to sulphur dioxide and ultimately to trioxide. The atmosphere eventually disgorges the resulting sulphuric acid; it descends with the rain to join that part of the sulphur of the same origin which combined directly to sulphates with the bases of the rocks of the volcano. Incidentally some hydrogen sulphide is reduced to native sulphur, which may come to rest in the volcanic craters and form deposits of economic importance. Selenium and tellurium sometimes accompany this native sulphur.

All intrusions give off sulphur compounds which are fixed as sulphides of many kinds, mostly pyrite, filling veins or impregnating adjacent rocks. Sometimes the sulphur is fixed as sulphates, *e.g.*, barite or anhydrite. Some of the persilicic waters reach the surface with a remaining load of hydrogen sulphide and local deposits of native sulphur may accumulate at the vent of the springs.

The basic rocks and the gas fluxing products form the raw material for the next big operation. When exposed at the surface to oxygen they yield sulphates, usually soluble sulphates—of iron, aluminum, zinc, calcium, magnesium, sodium, and potassium, and the sulphates wander to the sea—all except some difficultly soluble compounds like lead sulphate, or basic iron sulphate, which lingers behind. On the whole the alkaline sulphates predominate.

In the average rivers the sulphate radicle is present in relatively large amount. For the radicles $CO_3 > SO_4 > Cl$ is the rule though in rivers draining large sedimentary areas, the relations change to $SO_4 > CO_3 > Cl$. For the bases the following rule holds: $Ca > Mg > Na$.

In ocean waters this relation is reversed. We have $Cl > SO_4 > CO_3$ and $Na > Mg > Ca$. The quantity of sulphates discharged into the ocean is enormous and we may well wonder why the sea is not mainly a sulphate solution. As it is, it contains in the dissolved salts 7.69 per cent. of the sulphate radicle. The

reason is because there is along the littoral, particularly along muddy shores rich in organic matter, a continuous reduction of sulphates to sulphides. The rich shore fauna need sulphur and iron, combining after the death of the animals to iron sulphide. Sulphur mainly as iron sulphide is indeed very plentiful in the shore deposits; in fact sulphur is one of the few elements of the silt or mud which shows a relative increase compared to the amount in the igneous rocks. In some deep closed basins like the Black Sea similar reducing conditions obtain at the bottom and the result is a deep mud rich in iron sulphide.

This continual reduction of sulphates, then, is the reason why the sea water does not become overloaded with sulphates, and the main result is a relative concentration of iron and sulphur in marine mud deposits.

The story is not yet half told. Evaporation of sea water or lake water in closed basins precipitates calcium sulphate at an early stage, and results in practically all of our gypsum deposits. Considering the crust as whole they are unimportant. Economically they are supremely important.

In these beds of calcium sulphate meteoric waters loaded with hydrocarbons produce interesting effects. The calcium sulphate is reduced to sulphur, and thus are our most valuable sulphur deposits formed—simply by a side reaction, wholly negligible in a world-sense. Some geologists believe that deposits of sulphur may be formed in closed lake basins by bacterial activity, but this is not established with certainty.

The muds and silts are compressed, raised, and folded by geological processes to shales and sandstones. They are enriched in sulphur, largely as marcasite, and, therefore, fall an easy prey to oxidizing solutions which turn the sulphide again to sulphate and speed the latter again towards the sea.

The meteoric waters of the deeper circulation have not yet found mention. They do their part especially in searching the uplifted sediments, limestone, shale, or silt, and extracting sulphates from them when near the surface or sulphides of hydrogen, iron, copper, lead, and zinc where penetrating the sediments

in depth. At suitable places these metallic sulphides may be deposited and thus a certain part of the sulphur becomes temporarily fixed. Of such origin it is believed are the great zinc and lead deposits in limestone of the Mississippi Valley. Nickel, cobalt, and cadmium follow the metals mentioned.

A large part of the sulphur of the world is then continually in movement, changing from sulphide to sulphate with local reversions to native sulphur, and from sulphate back to sulphide again. Most of these processes go on in sedimentary rocks.

The Story of Vanadium.—A complete history of the wanderings of vanadium would be of exceptional interest. Unfortunately our information in regard to this peculiar element is not complete.

In small quantities the element is contained in all rocks particularly in basic rocks, not as a separate mineral like apatite, but as an admixture in magnetite, ilmenite, biotite, rutile, and pyroxene. It is foreign to acidic pegmatites and is apparently not concentrated by gas fluxing processes. Whether this is wholly true is doubtful. We may recall the close and unexplained association of roscoelite (vanadium mica) with gold and tellurides in certain deep-seated veins affiliated with intrusive rocks. As to the vanadates in oxidized veins their acid radicle has usually been attributed to a small percentage of vanadium in the wall rocks, but may it not more logically be derived from obscure roscoelite in the vein itself?

1. During the process of weathering a part of the vanadium of rocks and ore deposits goes into solution and becomes concentrated in limonite similarly to phosphorus but in smaller amounts. It is known, for instance, that bog-iron ores generally carry vanadium.

2. A large part appears to be concentrated in the sediments. The wide distribution of vanadium in the terrigenous sandstones of certain formations like those of the Red Beds of the southwestern states and the Permian of Europe has long been known.

3. Vanadium tends to accumulate in the silts and muds, even more than in the coarser sediments. Reference to this has been

made above and it looks as if the largest amount of the element lodges in these fine sediments. Perhaps it is carried along with alumina in colloidal suspension. The occurrence of vanadium in clays along with greater quantities of titanium has frequently been observed.

4. Finally a smaller proportion of vanadium is taken into solution by the surface waters, probably as calcium vanadate, and is carried to the sea. While vanadium has not been shown to exist in the sea water it certainly appears to be absorbed from this source by holothurians and ascidians as a substitute for copper or phosphorus in their blood. After the death of the animal the vanadium salts return to the sea water or become buried in the sediments. It is not at all unlikely that vanadium is concentrated from the sea water by other animals, perhaps those of lower orders. In this connection it would be interesting to ascertain if it ever appears in petroleum.

It is strongly suspected that plants also use vanadium perhaps as a substitute for phosphorus. In many places the ashes of plants, coals, and particularly asphaltic substances contain vanadium. It would seem as if a gradual concentration of vanadium had taken place during the development of asphaltum. One view frequently expressed is that coaly substances precipitate vanadium from meteoric waters, but it is perhaps even more likely that vanadium formed a part of the original organism. Bituminous shales often contain vanadium. The Mesozoic sediments of Peru are particularly rich in this metal. For instance, certain black shales in the Andean region of that country were sampled across 50 meters horizontal distance and all samples contained vanadium in amounts from 0.12 to 0.41 per cent.

When sedimentary rocks containing vanadium are percolated by meteoric waters—probably at considerable depth—they seem to yield some of the metal in soluble form which is again precipitated as vanadium mica (roscoelite) or potassium-uranium vanadate (carnotite). Some Mesozoic beds in Colorado, Utah, New Mexico and elsewhere contain deposits of this kind which have economic importance. The ores are later than the beds

which they follow, and are characterized by a very strange assortment of elements among which, besides the two already mentioned, are copper, lead, silver, barium, chromium, nickel, molybdenum and selenium. Igneous rocks are absent. Thus far no entirely satisfactory explanation of the mode of origin of these deposits has been formulated. Most of the elements just referred to are such as are known to be relatively concentrated in sediments. Chromium is one of these and it is evident that biochemical processes play some part in its concentration. It is not generally known for instance that the rich rock phosphates of Idaho and Utah in all cases contain notable amounts of chromium, often together with small quantities of nickel and vanadium.[8]

In this connection some reference should be made to the largest known vanadium deposit in the world—that at Mina Ragra, Peru. It appears to be a vein containing the sulphide "patronite"—really a mixture of three vanadium sulphides—asphalt, sulphur, pyrite (with nickel) and some molybdenum. I believe that this represents deposition by meteoric water which obtained its vanadium from Mesozoic sedimentary rocks.

To sum up, it is believed that vanadium was first moderately concentrated in fine sediments and that a second concentration has been effected by biochemical processes followed by a third concentration by meteoric waters and reprecipitation at suitable places. It is held that the second concentration and perhaps the third resulted in finely disseminated "patronite," owing to the combination of vanadium with sulphur likewise of organic origin. Still later processes of alteration resulted in such minerals as carnotite and roscoelite.

The association of uranium and vanadium is probably not accidental. Uranium has been found in the ashes of many fossil coals and it seems probable that this metal like vanadium is taken up by certain forms of plants.

It is well known that carnotite in sedimentary beds is one of the sources of radium, the others being various uranium minerals

[8] Personal communication from Dr. Frank Cameron.

including pitchblende, derived from salic extracts or gas fluxing processes. It is also known that certain gas wells in petroleum districts give off nitrogen and helium together with hydrocarbons. Considering that helium results from the breaking up of radium, is it not likely that the helium is derived from a uranium mineral disseminated in sandstones and shales forming part of the petroliferous series?

These " stories of the elements " could be multiplied, but I fear an adequate treatment would soon expand this address to the size of a volume. Enough has been brought forward to show that investigation along these lines are likely to be fruitful of results and may lead to important conclusions.

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SOME RELATIONS BETWEEN METAL CONTENT, LODE FILLING, AND COUNTRY ROCK.

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INTRODUCTION.

AN investigation was undertaken[1] in the endeavor to find what distinctive characteristics, if any, were associated with ore shoots. It was hoped that at least some clue might be found which might be of practical help in prospecting developed mines so that expenditure could be focused on favorable possibilities and improbabilities discarded. Unfortunately at the commencement of the work tin mining in general, and particularly in Cornwall, began to experience the acute depression under which it is still stagnating. On account of the general closing down of the Cornish mines, the writer was able to make an underground examination of only two mines. It will therefore be understood that any facts which may be brought to light have only a local bearing and cannot be accepted as general. Certain facts, however, suggest one aspect of the critical examination of ore bodies which may prove to be a profitable source of investigation—this may be summed up in the question, "What was the condition of

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[1] At the suggestion of Professor Frecheville.

the lode channel during the period when the tin content was deposited?"

Previous Literature.—Considerable work has been done on the characteristics of ore shoots and the localization of values from a general point of view. W. H. Weed[2] in summarizing the known features of ore bodies indicated two general factors: (1) influence of country rock on vein structure—the veins being affected in size and shape and probably to some extent in richness by the character of the lode channel fracture; (2) influence of country rock on vein filling.

Among other valuable contributions to the subject, particular mention may be made of the series of articles by various writers in a discussion in ECONOMIC GEOLOGY some years ago.[3] J. D. Irving opens the discussion by suggesting a very useful classification of ore shoots.[4]

F. C. Smith[5] refers to the difficulty of attempting any generalization which will universally apply, quoting a particular characteristic which has only a local application, as at the Holy Terror Mine, Keystone, South Dakota, where the gangue of the ore shoot is smoky quartz, that of the vein a white opaque quartz.

Reno H. Sales[6] in discussing the ore shoots at Butte, Montana, shows that the lodes are in crushed or fault zones in igneous rock, the ore shoots occurring as replacement of the fault zone. The localization of the ore shoots was apparently determined by the physical nature of the country rock composing the fault zone. "The size and richness of the ore bodies may have been influenced to some degree by the cutting off, or I might say damming back, of the mineral solutions, through the later development of impervious material along or within the fault zone."

H. V. Winchell[7] points out the importance of postgenetic (sec-

[2] W. H. Weed, "Influence of Country Rock on Mineral Veins," *T. A. I. M. E.*, vol. 31, 1902, p. 634.

[3] "Localization of Values or Occurrence of Ore Shoots in Metalliferous Veins," ECON. GEOL., vols. III. and IV., 1908–1909.

[4] ECON. GEOL., vol. III., p. 145 et seq.

[5] *Loc. cit.*, p. 224 et seq.

[6] *Loc. cit.*, p. 386 et seq.

[7] *Loc. cit.*, p. 425 et seq.

ondary) ore shoots as well as paragenetic (primary) shoots. He believes that all the possible agencies which "operate upon it after its first formative period tend to accentuate its peculiarities, emphasize its idiosyncrasies and separate the valuable from the worthless, thus creating ore shoots."

Hjalmar Sjöpgren[8] and A. C. Lane[9] indicate the gradual diminution of copper in depth in the Scandinavian and Lake Superior copper districts respectively.

A detailed geological examination of any mining region appears generally to bring to light certain inherent peculiarities of each ore shoot, as distinct from the main lode material—this peculiarity may be either mineralogical or structural, mainly the former. But this peculiarity is of such an indefinite and unreliable character that it is rarely a practical and sure guide in mine development. It would serve no additional purpose to continue to quote examples broadcast from the numerous papers on the subject.

In Cornwall perhaps the earliest detailed work of this character was that of W. J. Henwood.[10] As a general rule he states that the lodes are seldom rich in the hardest or quartzose part of the country. Granite is favorable if it is medium grained, feldspar phenocrysts greenish, pink, or brown, and their borders indeterminable or passing gradually into the groundmass. If the joints which are parallel to the strike of the lodes fall towards it in descending, it is a favorable sign; if similar joints separate from it as they go downwards, it is unfavorable. Droppers and feeders bear a similar relation to their equivalent joints. Many transverse joints in the lode seem to be unfavorable, and often a shoot of ore is cut off by a joint across the lode. After describing the favorable characters of slate and elvan, Henwood shrewdly concludes "yet all these appearances, whether kindly or unfavorable, are but local, and are often confined within very narrow limits, and in the same rock there is frequently an altera-

[8] ECON. GEOL., vol. IV., p. 637 et seq.

[9] *Loc. cit.*, p. 158 et seq.

[10] W. J. Henwood, "On the Metalliferous Deposits of Cornwall and Devon," *Trans. Roy. Geol. Soc. of Cornwall*, 1843.

tion in the lodes as soon as the characters of the rock are changed."

Henwood also notes that the steepest parts of the lode are always the most productive, and that the ore shoots dip away from the main mass of the granite. Moissenet[11] notes that "the bearing of the rich parts of the lodes corresponds to the direction of the stratigraphic system with which the fracturing of the earth in the region in question is connected." This observation Collins[12] refutes as being quite unnoticeable in deep mining. Collins points out that the junctions of unlike rocks are favorable for ore values, as are the acute junctions of two lodes. He notes also that the rich parts of parallel lodes are opposite (*i.e.*, in the direction of the main cross courses). As the lode is approached, Collins points out that the country rock in the granite changes, becomes "softer, sometimes silicified, more often pyritized or otherwise mineralized in its neighborhood." Richer parts of lodes usually have the country wall rock showing discoloration, oxidation, hydration, softening or hardening, or general mineralization by pyrite. Roughness, smoothness, or porosity of the rock bounding a fissure appear to influence deposition—partly through modification of surface tension, partly through influence on the flow of chemically reacting substances, and partly through influence on crystallization or mechanical deposition —varying rock conditions will give varying values. Finally Collins shows that the whole of the tourmaline-bearing area includes all the tin and tungsten, but yet we may have tourmaline without tin, but not tin without tourmaline, and tin without tungsten, but not tungsten without tin.

All this shows the difficulties of attempting to pick out the true evidence of "favorability" from the mass of accumulated and heterogeneous evidence.

[11] L. Moissenet, "Observations on the Rich Parts of the Lodes of Cornwall," transl. by J. H. Collins, 1877.

[12] J. H. Collins, "Observations on the West of England Mining Region," *Trans. Roy. Geol. Soc. Cornwall*, vol. XIV., 1912.

GENERAL FACTORS GOVERNING LOCALIZATION OF VALUES.

The general concensus of recent geological opinion is to the effect that temperature is the main factor governing the deposition and zoning of ore bodies, and that pressure is probably of little or no importance. It is to the influence of temperature that we must look in the main for any permanent explanation of the successive crystallization of minerals There is still considerable doubt as to the actual succession of our metallic minerals, the succession apparently varying slightly in different areas.

However, there is an apparently universal group-order of crystallization: (*a*) tin-tungsten as high temperature deposits, (*b*) copper-iron sulphides, (*c*) zinc-lead-silver to gold ores, and (*d*) siderite and other carbonates as low temperature deposits.

Local variation occurs within the limits of each group, which is particularly common in the sulphide group. The relative concentration of each sulphide in the original ore solution may be an important factor in determining the order of deposition of these sulphides.

It is now generally considered that the zonal arrangement of mineral deposits about the igneous intrusion to which they are magmatically related is due to heat given off from the magma, so that the successive order of mineral deposition tends to a zonal arrangement of minerals, conforming somewhat to the parallel isotherms around the granite surface. The continuance of the metalliferous phase, accentuated by the evident variation in composition of the ore-bearing solutions, with gradually decreasing temperature and lowering of the isotherms, would cause the superposition of one mineral group upon those higher in the temperature scale. This superposition may go on to such an extent that we may entirely lose sight of the influence of temperature.

A striking instance of the manner in which an ore shoot may conform to the granite boundary is afforded by the copper shoot at the Tresavean Mine, Cornwall. This ore shoot is parallel

to the granite-hillas contact, the upper limit of the ore shoot actually conforming to the contact for the most part. The upper limit of the tin shoot below the copper also appears to follow the direction of the granite surface.

In 1843 Henwood[13] recorded as a general rule that the ore shoots dip *away* from the granite mass, that is, conform somewhat to the direction of the granite surface.

E. H. Davison[14] notes that his three types of tin and tungsten veinstones are apparently related in their distance from the surface of the underlying granite, and their promixity to the crest of the granite mass.

This zonal arrangement is horizontal as well as vertical. In Bolivia, W. Myron Davy[15] has shown the horizontal or linear arrangement of the tin-tourmaline, tin-silver, and silver veins outward from the granite center.

In the Heemskirk-Comstock-Zeehan area of Tasmania, Twelvetrees and Ward[16] recognize three distinct zones: (*a*) granite zone, (*b*) contact-metamorphic zone, and (*c*) transmetamorphic zone, each with its particular ore group. L. K. Ward in summarizing their views states,[17] "So the nature of the variations in the lode-matter, as observed in a horizontal direction, is sensibly identical with that which would be visible in a vertical direction, could we but follow a single lode downwards towards its source, if the materials supplied to the several fissures throughout the area have been approximately the same." The general result appears to have been that cassiterite ores have been precipitated within the igneous boundaries by the ascending vapors and solutions which, as they traversed the successively cooler zones, have deposited in turn magnetite or mixed mag-

[13] W. J. Henwood, "On the Metalliferous Deposits of Cornwall and Devon," *Trans. Roy. Geol. Soc. Cornwall*, 1843, p. 194.

[14] E. H. Davison, "A Study of Cornish Veinstones," *The Mining Mag.*, 1920, p. 244.

[15] W. M. Davy, "Ore Deposition in the Bolivian Tin Silver Deposits," Econ. Geol., vol. XV., 1920, p. 463 et seq.

[16] Vide Geol. Surv. Tasmania, Bull. 8, pp. 63–67.

[17] L. K. Ward, *Proc. Aust. Ass. Ad. Sc.*, vol. XIII., section c, pp. 153–154.

netite and sulphides, then pyritic zinc and lead ores, and finally sideritic lead ores.

In Cornwall, the ore deposits are mainly grouped on the side of the granite mass showing the shallowest angle of dip of the granite surface. This feature may probably be explained by the greater likelihood of fractures of adjustment occurring above the shallow-sloping surface of the granite than around a steep surface, and also by the probability of the ore reservoir being rather more immediately beneath the shallow-sloping surface.

In a general way, the Cornish ore groups—tin, tin-tungsten-copper, copper, lead-silver, and siderite—show a rough grouping numerically around the granite masses, the distance from which increases in the order tin to siderite. The limits of each group were probably governed by the upward and outward drop in temperature. At a number of mines in the Carn Brea area in Cornwall, the copper lodes in depth become tin bearing—again an apparent temperature relation, the lowering of temperature within and around the granite. Other minerals also appear to show this zoning, as chlorite and tourmaline, the former being much more abundant in the upper portions of the lodes, the latter in the deeper part.

CONCEPTIONS OF LODE FORMATION.

It has long been recognized that simple fissure filling does not conform strictly to the evidence afforded by many veins and lodes, therefore an attempt was made to obtain a clearer conception of the mechanics of lode formation.

Recently, Taber[18] has conclusively demonstrated the development of veins by force during crystallization—"that veins may be deposited from solutions entering along extremely small passages, and that the growing veins have made room for themselves by forcing apart the inclosing walls." It appears that "so long as a crystal surface is in contact with a solution supersaturated with respect to that surface, growth will continue no mat-

[18] S. Taber, "Mechanics of Vein Formation," *Trans. Am. Inst. M. & M. Eng.*, vol. LXI., 1919, pp. 3–30.

ter how great the pressure or strain may be," and that "when a crystal grows in a direction in which growth is opposed by an adjacent solid, it is due to the fact that the material necessary for growth is able to diffuse between the crystal and the other solid." He does not use the term "force of crystallization" as amorphous minerals, as limonite, appear to possess this property of exerting force during precipitation; rather does it appear to be some function between the solid and the solution with respect to which it is supersaturated.

Taber summarizes conclusively the evidence that veins are not due to filling of open fissures. All the old accepted criteria for the recognition of open-fissure filled veins, as drusy cavities, banding, and crustification, Taber shows, can be obtained in veins which made room for themselves by pushing apart their walls. The present writer, however, would picture the same effect produced by the successive supersaturation of different minerals with respect to the ore solutions, with fall in temperature.

Inclusions of country rock and brecciation of earlier vein material may be often aptly explained by "growth during crystallization" of the later vein minerals. Besides this mechanical displacement of the surrounding minerals, Taber points out that displacement by solution of the inclosing rock is perhaps of greater importance. "Mineral crystals in contact with supersaturated solutions must grow, and, if surrounded by other minerals, the latter will be mechanically displaced, or, if they are rendered more soluble by pressure, they may be removed in solution and deposited elsewhere. The mechanical displacement of individual minerals in a compact rock would necessitate enormous forces; the pressure per unit area would have to be very much greater than that required in separating the walls of a growing vein. . . . Therefore, when crystals develop in compact rocks, the necessary space is usually obtained through solution rather than mechanical displacement."

F. L. Stillwell[19] has recently shown that growth during crys-

[19] F. L. Stillwell, "The Factors Influencing Gold Deposition in the Bendigo Goldfield," Bulls. 8 and 16, Advis. Council of Sci. and Industry, Commonwealth of Australia, 1919.

tallization, by forcing the walls apart, is an important factor in the development of the quartz reefs of Bendigo, Victoria.

That growth by the force exerted during the crystallization of the vein matter is of importance in Cornish vein formation, the present writer has become convinced from the field and microscopic evidence studied.

The walls of the great majority of the lodes in Cornwall show alteration and replacement; the resulting rock is often an integral part of the lode itself. Apart from this mineralogical change, the lode walls often show a structural alteration, or, as Collins[20] terms it, a "sheeted" structure. Collins classifies the lodes as:

(*a*) An ordinary fissure vein-filling in a fairly compact rock.
(*b*) The same in a "sheeted" country rock.
(*c*) A sheeted mineralized belt associated with one or more main veins.
(*d*) A "sheeted" earthy or clayey vein filling in a "sheeted" country rock.
(*e*) A "sheeted" mineralized belt not associated with any main vein.

McAlister[21] classifies veinstone structures into:

(*a*) Fissure, or a series of close parallel fissures filled with metalliferous or other minerals.
(*b*) Mineralization of the walls of the lode by impregnation or metasomatic replacement.
(*c*) Mineralization of crushed rock or breccias contained in the lode.

Under heading (*a*) McAlister points out[22] that often "the original character of the fissure is obscure, as sometimes the cracks or joints are so close together that the intervening layers

20 J. H. Collins, "On the Origin and Development of Ore Deposits in the West of England," *Jour. Roy. Inst. Corn.*, No. 38, 1892, p. 91.

21 D. A. McAlister, "Geol. Aspects of Lodes of Cornwall," ECON. GEOL., vol. III., 1908, p. 210.

22 D. A. McAlister, "The Geol. of Falmouth and Truro and of the Mining District of Camborne and Redruth," Hill & McAlister, *Mem. of G. S. of E. and W.*, 1906, p. 132.

of country rock are completely altered, while at the same time the fissures have been obliterated. Sometimes where the lode appears to be massive, minute lines of rifting can nevertheless be seen, through which, no doubt, the changes in the walls of the lode were effected." That is, the final "fusion" of a number of parallel veins by the entire replacement of the intervening country will give the appearance of one "fissure vein."

Regarding breccias McAlister suggests, "These breccias may also originate in the swift vibratory movements accompanying earthquake shocks, or may result from direct pressure without faulting."

J. A. Phillips,[23] in discussing the formation of the Cornish lodes, notes that "in many instances the original opening would appear to have been a mere comminuted fracture of the rock in a given general direction, between the several planes of which a deposit of mineral substance has subsequently taken place through chemical agency. The final result in such a case will be a brecciated veinstone of the kind so constantly met with in mineral districts." He pictures the crystallizing minerals as pushing their walls apart, thus making room for themselves and widening the original fracture zone—this appears to have been a real factor in the development of a number of the veins in Cornwall.

That replacement has played an important part in the development of Cornish lodes is undoubted. That growth by the force exerted by the growing mineral crystals has also taken place can be noted in practically every vein that the writer has examined, particularly in those parts which have been looked upon by many as open-fissure fillings.

It may be logically accepted that the original lode "channels" were precisely similar, structurally, to fault fissures we see today. Crosscourses, at least where met with in granite, consist of a series of close parallel shear planes. This sheared granite is not a fault breccia in the usual sense—it is merely sheeted granite, often somewhat kaolinized owing to circulating waters. On

[23] J. A. Phillips, "Lodes of the Min. Distr. of Cornwall," *Q. J. G. S.*, vol. XXXI., 1875, p. 341.

this basis then, Collins's classification of the Cornish veins records the extent to which the sheeted lode-channel has been replaced by the mineral solutions.

Just as in the crosscourses no open fissures or spaces have been met with, so in the original lode channel there were no open fissures. In any case it would be difficult to conceive of any open spaces remaining in such a sheeted fracture zone. The ore solutions ascended along the fracture planes of the comminuted country rock, replaced the rock on either side and at the same time the veinstone "grew" by forcing the fracture walls apart. Replacement will often remove all signs of the original sheeted character; the result may be a so-called "fissure filling." The method of this replacement accompanying the crystal growth has been already suggested above by a quotation from Taber's[24] work.

During lode formation there has been a definite sequence of mineral deposition. In general, tourmaline crystallized before quartz. Tourmaline replaced a large amount of the orginal granite, and "grew" to a certain extent, so that the lode at the close of the tourmaline stage may have consisted of a series of parallel tourmaline veins. Later, quartz replaced the remaining granite, and in part the tourmaline, and also grew during the process by forcing the walls still further apart, but yet in many cases preserving the original parallel structure of the tourmaline. Often the final appearance is that the tourmaline veined the quartz, but microscopic examination will show the quartz to be later. In a similar way "crustification" in general of other minerals, as chlorite, may be explained.

In the writer's opinion, each mineral either replaced the already existing ones or made room for itself by forcing the walls apart, according to the physical state of the already existing mineral aggregate—both replacement and growth during crystallization may go on side by side, at the same time.

RESULTS OF WORK.

The writer concludes that the original lode channels were sheared granite zones similar to the crosscourses in granite;

[24] *Op. cit.*, p. 29.

within this sheared granite there were no open fissures. The sheared or sheeted granite was replaced by the lode minerals. The mechanics of this replacement, as pictured by Taber,[25] is the solution of existing minerals under the pressure exerted by the growing minerals. As these primary minerals are taken into solution they may become an integral part of the lode solutions and may be re-deposited as different minerals—probably much of the chlorite has this origin. This mechanical replacement was accompanied by mechanical fissure growth, or widening of the lode channel. Many quartz crystals show the influence of both methods of growth—growth by forcing aside the earlier minerals, and growth by replacing those earlier minerals.

The actual period of mineral deposition is assumed to be comparatively short, according to geological time. Recently Cronshaw[26] has suggested that the metalliferous period in Cornwall extended from the period of igneous activity (Carboniferous), up to early Tertiary. The relation of the ore-mineral zones to the granite surface would indicate that the ore deposition is directly dependent on the rate of cooling of the granite mass. It is not likely that this cooling would transcend the limits of even one geological period, and certainly not continue to Tertiary times. The writer does not believe the mineral phases to be intermittent, but pictures the mineral deposition as continuous from beginning to end. Slight movement apparently took place in the lode during crystallization and was probably in part a concomitant of the growth by the force exerted by the growing crystals. Therefore, in the sense that they have not been formed by successive vein reopenings, the lodes are not complex. The writer cannot uphold Cronshaw's ten intermittent phases of mineral deposition, but believes there was only one continuous mineral period, the length of which at any particular point was governed by the time the temperature took to drop from that necessary for the deposition of brown tourmaline to that for fluorite.

The mineral sequence is governed by the temperature at which

[25] *Op. cit.*, p. 29.

[26] H. B. Cronshaw, *Bull. Inst. of M. M.*, No. 204, Sept., 1921.

each mineral becomes supersaturated with respect to the ore solutions as they ascend. These ore solutions as they emanate from the magmatic reservoir remain of practically the same composition from the beginning to the end of the metalliferous period, except perhaps for a slight occasional local variation. As these solutions move from hot to colder zones they gradually become poorer in the higher temperature minerals, owing to crystallization, so that the solutions become more and more simple in composition. How far the phase rule will apply would be difficult to estimate, but it would seem probable that each mineral present in the ore solutions would affect the crystallizing temperature of the others. The mineralogical complexity of the lodes at any particular point is due to the progressive lowering of the isotherms at that point, and the consequent superposition of lower temperature minerals upon those higher in the temperature scale. The table shows the apparent sequence of crystallization of the minerals in the lodes examined. The evidence on which this table is constructed will be found in a later part of this paper.

Throughout the lodes examined, the cassiterite was found to be related in its temperature of deposition to the blue tourmaline and early chlorite. Primary feldspar appears to have occasionally exerted a slight selective influence upon it, some cassiterite replacing the feldspar.

The wider parts of the lodes showing maximum mineralization are the positions of greatest tin values, and particularly is this the case where there is much tourmaline peach.[27] Extremely fine-grained tourmaline peach is, however, rarely stanniferous, the tin being rather associated with a slightly coarser material into which quartz ofter intrudes. In general, those parts of the lodes in which the tourmaline peach shows a more even replacement throughout by later minerals are the richer.

The more laminated, fractured, and splintery the lode, the

[27] Peach—a local name for a fine-grained rock of simple mineralogical composition, either wholly of tourmaline (tourmaline peach) or of chlorite (chlorite peach) or of both.

better in general are the tin values. These characteristics are probably an indication of the severity of pre-mineral shearing, as it is only in the more laminated and wider parts of the lode that fracturing becomes noticeable. On the other hand, where the lode is represented by only one or more narrow "stringers" traversing an altered hard silicified granite or capel,[28] or where the lode consists merely of dark hard massive capel between two walls or "joints," the tin content is always poor—probably an indication of the absence of severe pre-mineral shearing.

The junctions of lode branches are almost without exception of very high-grade ore. This may be because of the greater volume ascension of mineral solutions at these junctions; here also the lode is generally wider, indicating either a greater width of shear zone or greater replacement and growth—probably a result of all three.

All these lode characteristics depend primarily on the porosity of the original channel, the severity of shearing, or the closeness of the sheeted structure. More especially, however, the tin values appear to be related to the porosity at the moment the tin crystallized. The greater the porosity, the greater is the ease with which the tin and later minerals can crystallize, and the greater will be the mineralization. Mineralogically, the more complex the lode, the better the tin values; where pyritic minerals are distributed through the lode the tin values are generally good. A maximum mineralogical complexity is an indication of the porosity of the original lode channel, and the greater the original porosity the longer will be the period during which minerals can crystallize with ease throughout the lode.

As the main bulk of the tin was deposited at the same time as much of the blue tourmaline, the tin will be associated with the tourmaline in the more porous parts of the lode. Tourmaline and tin being the two earliest minerals to crystallize, they will

[28] Capel—a local name for an altered granite occurring along the lodes. It is granitic in texture, dark-colored, but contains white unreplaced quartz. All the feldspathic constituents of the granite have been removed, and much of the primary micas. Usually the feldspars have been replaced by sericite and later quartz, sometimes by tourmaline or chlorite.

be deposited at the points where the lode channel had been subjected to the most severe shearing—the most porous parts of the original lode channel. It would appear then that a critical detailed study of each lode channel is necessary in order to realize the condition of that lode channel at the instant the values were deposited. This may eventually prove a profitable line of investigation of lodes in general, when all the changes and forces entering into the formation of an ore deposit are understood more clearly. It will be a question of understanding the full physical and mineralogical effect that each successive mineral may have upon the condition of the lode.

At present all that can be said is that favorable and unfavorable characters may be found along the lode on one level. Sometimes the lode may show an unfavorable character throughout, as in the Main Lode, South Crofty, 290-fathom level. In this case it is due to absence of blue tourmaline, and so only poor tin values are met with. On the other hand, practically every rich lode will show an unfavorable character away from the ore shoot, and in such places there is nothing to indicate that by driving one way or the other good ore will be encountered. The barren veinstone close to an ore shoot is precisely the same as that in an entirely unfavorable lode, except in so far as the favorable character may increase as the values are approached.

DETAILS OF LODE STUDY.

Method of Procedure.

As the work was to be based on known value relations, it was carried out in conjunction with assay plans. If the assays were unknown, the lodes were not investigated. The extent of the work was therefore considerably narrowed in its scope of lode type.

At the South Crofty Mine the 290-fathom, 260-fathom, and 180-fathom levels were investigated. The lode at the Tresavean Mine was investigated in the tin-bearing zone—370-fathom, 345-fathom, and 320-fathom levels.

On each drift samples were taken at definite points along the lode where the assay values were known. At each point samples were taken across the lode and of the country on either wall, where obtainable, so that mineralogical and physical variations might be critically studied. In this way it was hoped some definite relation might be found between the metal content, the lode filling, and the country rock.

The two mines will be considered separately. Both are similarly situated on the boundary of granite masses—the South Crofty mine on the border of the Carn Brea granite outcrop, the Tresavean mine on the eastern border of the Carn Menellis outcrop further south.

South Crofty.

The levels examined in the South Crofty mine are well below the granite-killas contact.

290 Level, No. 3 North Lode.—For a width of 1–2 feet, the lode possesses a laminated character, but alteration of the granite extends over a width of 10 feet. Between the quartz laminæ is a bluish green peach, consisting in part of tourmaline, in part of chlorite. Laminæ of highly silicified granite are occasionally noted, as well as of fluorite. The latter is evidently the last mineral to be introduced into the lode. All these laminæ are non-persistent.

The country rock is somewhat altered; it is silicified, tourmalinized, sericitized, and chloritized. Approaching the lode along the crosscut this alteration may be definitely noted at about 10 feet from the lode, by the introduction of numerous quartz-chlorite-tourmaline veins, actual replacement taking place only on the walls.

The lode minerals replaced a fractured granite consisting of pink and buff-colored feldspars (orthoclase and microline), quartz, brown tourmaline, and micas. The brown tourmaline is evidently secondary after biotite and probably after feldspar in part. The evidence points to its being a primary mineral in the sense that it is found practically throughout the granite masses even away

from the vicinity of the veins. Still, some of it may be secondary in the sense that it is directly due to the lode solutions—this is a high temperature variety of tourmaline. With respect to brown tourmaline the definitions here noted of *primary* and *secondary* will be used throughout this paper—strictly speaking both are secondary.

The mineral sequence is: blue tourmaline and tin, quartz and chlorite, and fluorite. These minerals replaced feldspars and ferromagnesians and sometimes quartz, but often much of the quartz is unaltered, except in the massive tourmaline peach. Growth by force exerted on surrounding minerals also took place during crystallization.

The tin ascended with the blue tourmaline, both replacing the feldspars. Rich tin ore is often associated with feldspar-bearing laminæ (unreplaced granite feldspars). The tin-tourmaline phase of deposition apparently continued to the quartz-chlorite phase, but with diminished vigor; the chlorite may be looked upon as the cooler stage of the tourmaline phase, in which the boron content has disappeared. The last of the tin practically crystallized with the first of the chlorite and quartz. During and succeeding the growth and replacement by tin and tourmaline there were slight shear adjustments, probably brought about as relief to the growing crystals. Along the fractures so formed in the quartz (residual or unreplaced) a little fine tin crystallized and some secondary quartz and occasionally chlorite.

The chlorite evidently persists throughout the quartz phase, and continues for a very short period subsequent to the quartz. Fluorite in part replaces feldspar (residual), is always interstitial to the quartz and generally restricted to the minute zones of granulation (the relief-fractures in the original quartz); it appears quite distinct to the tin-bearing phase.

The quartz, besides replacing feldspars and a little tourmaline, also grew by force, pushing the earlier minerals aside, and often showing idiomorphic boundaries. Occasionally it crystallized in optical continuity about original quartz.

The lode is richest where it is widest; the rich tin ore is associ-

ated with the tourmaline and the feldspar-bearing laminæ. Feldspar may possibly exert a selective influence on tin. Fluorite is abundant in the wider, richer parts of the lode, but it has no real influence on the tin, being later and sporadic in occurrence. It is noticeable that in parts of the lode where quartz and chlorite occur alone, without any tourmaline, there is no tin. In the narrow poorer portions of the lode the original shearing is also less. The tin often runs in narrow non-persistent bands with unreplaced feldspar.

290 Level, No. 2 North Lode.—Laminated structure extends over a width of between 1 and 3 feet, but quartzose ore is from 2 to 6 feet wide. The lode structure, mineral content, and the characteristics of the rich tin parts are in every way similar to No. 3 North Lode, and the same mineral succession may be made out. The laminated character of the lode is again due to the original sheeted character of the lode channel, and is made striking by the large amount of tourmaline peach present.

Occasionally a part of the lode carrying comparatively low tin values is entirely dark and massive, with much tourmaline. The laminated part of the lode is apparently better defined and more regular where the tin content is highest. The tin is generally more intimately associated with the tourmaline peach. Alteration of the country rock is confined to the lode walls.

290 Level, Main (?) Lode.—This lode is exposed for about 600 feet without profitable ore, and is characterized by a hard, fine-grained, massive structure. The "leader" is mainly of quartz and chlorite, often intimately aggregated, but occasionally the predominance of chlorite or quartz may give an indistinct parallel lamination. The lode is for the most part dark colored; traces of sulphides (pyrite, chalcopyrite, and arsenopyrite showing alteration to hematite) are occasionally met with. In places the lode contains unreplaced feldspars, fine, tough, and buff colored.

In the main "leader" only a little primary brown tourmaline is preserved, and this is veined by quartz. In places chlorite may be noted replacing feldspar, muscovite, quartz, and brown tour-

maline, the replacement proceeding from shear planes. The unreplaced feldspars generally show incipient kaolinization and sericitization. Occasional small grains of tin may be seen with chlorite and feldspar.

Quartz was one of the last minerals to crystallize, replacing probably the more severely sheared rock, and in part growing during crystallization; it often pushed the chlorite towards its crystal boundaries, but in general preserved the original trend of the chlorite. Wherever chlorite occurs, the quartz is fine-grained; the clear quartz is coarse-grained. This is probably due to the fact that the original chlorite in part replaced a shattered material, the quartz completing the replacement; primary quartz may also have been included in the shattered material. There is no evidence for believing that secondary quartz of different grain is of different age. The very fact of the chloritic material being pushed to one side during growth of the coarser quartz would tend to accentuate this crushing.

Fluorite probably accompanied the quartz and crystallized with the last of that mineral. The sulphides were more closely associated with the chlorite in age.

The capel along the walls is a quartz-chlorite rock. The granite country generally shows much secondary mica. Typically it consists mainly of abundant feldspar (orthoclase, plagioclase—oligoclase to andesine, and a little microcline), a fair amount of quartz and muscovite with a little reddish-brown biotite, and accessory apatite. Brown tourmaline is probably after biotite, but is earlier than all the succeeding secondary minerals. The feldspars for the most part show slight sericitization and kaolinization; in the capel where quartz has replaced the whole of the feldspar the sericite is retained as inclusions in the quartz. Much of the feldspar has been replaced by chlorite, which often veins the rock; a little has altered to muscovite (gilbertite and lepidolite). Lepidolite is associated with much included secondary pink tourmaline (rubellite) and appears to be secondary to it. The rubellite is secondary to feldspar; in places it may be noted only as an incipient pink, cryptocrystalline secondary ag-

gregate in feldspar, occasionally showing further alteration to muscovite (lepidolite). Gilbertite is a very common mineral replacing feldspar and occurs in considerable amounts. It often changes first to sericite, which later becomes incorporated into coarse flake-aggregates of gilbertite. These secondary muscovites are occasionally replaced by fluorite, which is later than the quartz, and probably later than the gilbertite and lepidolite, which are rather low-temperature minerals resulting from the action of lithia- and fluorine-bearing solutions. The position of rubellite is doubtful; it may be a low-temperature form of tourmaline, but yet too high for lepidolite. The sequence in this case appears to be: rare tin and sericite; chlorite, rubellite (?); quartz; quartz, gilbertite, lepidolite, fluorite, and sulphides.

The little tin that is present in the lode is associated with early chlorite; it probably accompanied sericitization, and crystallized in feldspars, which were later replaced by quartz. The lode was apparently formed after the main tin-tourmaline phase of the other lodes on this level. No blue tourmaline peach nor tourmaline capel occur; the tourmaline is represented by its probable low-temperature equivalent, chlorite. The lode is essentially a low-temperature formation; the isotherms had been considerably lowered before the commencement of its formation. Being formed at a lower temperature than the main stanniferous pneumatolytic temperature, no tin content is to be expected.

260 Level, No. 1 North Lode.—The laminated part of the lode is often of considerable width, sometimes up to 5 feet, while irregular quartzose veinstone extends this width in places to 10 feet.

Throughout its length the lode is fine-jointed and splintery in character; the jointing is transverse, longitudinal, and horizontal. The lode generally consists of dark blue to black tourmaline laminæ and chlorite peach in quartz. In places the lode is almost purely quartzose, but with thin tourmaline "ghost" bands, and often some irregularly distributed unreplaced pink feldspars. The hanging wall is occasionally well defined, but generally there is a gradual transition of lode to country rock. Sometimes the

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lode consists of merely two or more parallel laminæ in silicified granite, in which case the values are always poor. Hematite is rather common in both the chlorite and the tourmaline peach; it may be a primary deposition from the ore solutions or secondary after arsenopyrite. Fluorite comes in sporadically as the last mineral to crystallize.

In the granite country rock the feldspar often shows the same alteration to pink tourmaline (rubellite), lepidolite, and gilbertite previously described. In places the rubellite is associated with a little cassiterite which probably comes in near the end of the tin phase. In places the feldspar has altered to a fine-grained aggregate of sericite; in the granite feldspar is either entirely replaced by quartz, or a structure resembling an intergrowth results. Fine sericite is commonly left in the quartz as a "ghost" of the original feldspar. Occasionally fluorite replaces the muscovite, feldspar, and chlorite. The micas, primary and secondary, often show further alteration to chlorite. This alteration is especially noted where the quartz shows granulation; chloritization followed the line of least resistance. Quartz-chlorite veins with fluorite are common in the granite. Chlorite has a wide range of crystallization, having commenced before quartz, and continued to about the end; fluorite was deposited with the last of the quartz.

The tourmaline peach in the lode is generally a fine-grained, felted, gray-blue tourmaline with occasional large crystals, showing part replacement by quartz. Replacement may often commence from numerous isolated points in the tourmaline mass, and grow by pushing aside the surrounding tourmaline, so that often the tourmaline surrounding the quartz crystals may be densely packed or orientated tangentially to the quartz boundaries. This dense packing is particularly noticeable where quartz has crystallized at points along the minute fractures from which the original tourmaline had replaced the granite. Numerous prisms of brown tourmaline often occur, slightly coarser than the blue tourmaline, which is found as a marginal zone or alteration of the brown tourmaline. The brown tourmaline is always earlier than the blue

variety; some is residual from the replaced granite. The peach is a replaced granite, frequently with all signs of primary quartz removed; sometimes a little unreplaced quartz is preserved, easily confused with the later secondary quartz. The sericite ghosts of original feldspars may be noted occasionally, probably replacing the feldspars left unreplaced by the tourmaline. The tourmaline around the minute veins from which it apparently came is finer and denser than that in the rock-mass.

Often a certain amount of chlorite accompanies the quartz, sometimes replacing the tourmaline, producing a tourmaline-chlorite peach. The persistence of original fractures as planes of weakness may in this case be noted by quartz along the original pre-tourmaline fractures. In one instance the chlorite appears to be much earlier than the quartz, showing rather high double refraction and unusual micaceous structure quite unlike the chlorite accompanying quartz. It is probably a relatively high-temperature chlorite, as the included tin is intimately associated with it.

The mineral sequence appears to be: brown tourmaline; blue tourmaline with tin, ending with micaceous chlorite; sericitization of granite walls and slight alteration of feldspars to pink tourmaline; secondary muscovites (gilbertite, lepidolite); quartz and chlorite; sulphides and fluorite.

The tin is generally associated with the peach, mainly with the tourmaline peach, or the tourmaline-micaceous chlorite peach. Where the tin is associated with quartz, the latter may be noted as replacing the tourmaline rock. This lode has comparatively little associated tourmaline capel along its walls, the replacement being rather by micas and quartz. The lode itself, however, is characterized by considerable tourmaline peach. The concentration of the tourmaline and the earlier stanniferous solutions along the actual lode channel, not through the walls, may be in part the cause of the rather high tin content. Tourmaline and later minerals (sericite, chlorite, and muscovite) give an apparent suggestion of increasing in the country rock with the tin content.

The best ore is perhaps associated with a "splintery" character in the lode, the tin content diminishing where the lode becomes harder and more massive, or approaches the nature of capel. This splintering of the lode may be an indication of the extent of the original fracturing in the lode channel. This variation of structure with values is not invariable or definite, except where the lode becomes quite capel-like, when the tin content is always low.

Mineralization in this lode channel commenced at a relatively high temperature with crystallization of prismatic brown tourmaline, and continued to the end phase of quartz and fluorite. It therefore embraces the whole period of tin deposition.

260 Level, "A" Lode (No. 2 North Lode).—This lode was driven east of the crosscut, and for the first few feet was high grade, but soon became unpayable. Diminution of tin content is accompanied by diminution of width, and in the end of the level there is only a small quartz-fluorite veinlet in silicified granite. Near the crosscut where the best tin ore is, the lode is 6 feet wide and is similar structurally and mineralogically to No. 1 North Lode. Where the lode becomes valueless, tourmaline cuts out, the lode becomes thin and is represented by coarse quartz and fluorite with a little pyrite and some chlorite in the country; these are the later minerals of the ore solutions. The lode contains numerous hematite threads throughout, probably due to secondary leaching of sulphides.

180 Level, Lode 400 Feet North.—The "leader" is from 12 to 18 inches wide and shows a faintly laminated structure where the width is greatest, but loses this character with decrease of width, becoming practically a quartz-tourmaline capel. The best tin ore is found near the crosscut where the lode is 18 inches wide, faintly laminated, but mainly an aggregate of hard vitreous quartz in a fine siliceous tourmaline groundmass. In the end of the level where the tin content is negligible, the lode is practically a tourmaline-quartz capel.

The country rock along the lode shows the same alterations as those already indicated in other lodes; the mineral sequence is the same.

Tresavean Mine.

Work at this mine has been recently recommenced after a lapse of twenty years. The old copper workings in the granite

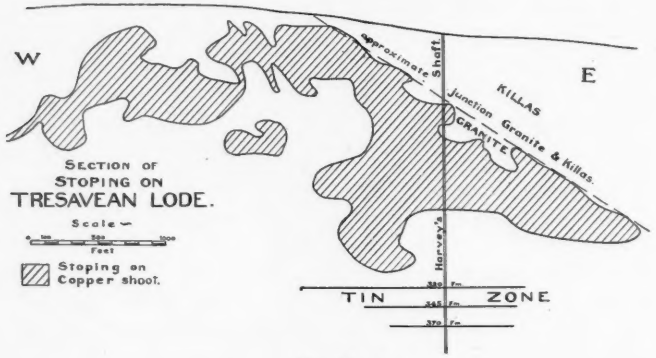

FIG. 66

at and below its juction with the killas (Fig. 66) are now inaccessible, the new work being carried out in the underlying tin zone. In this zone three levels have so far been driven—the 320-, 345-, and 370-fathom levels. These were the levels examined.

The hanging- and foot-walls are rather well-defined throughout. An average lode-width of 4 feet is maintained, but the tinstone goes into the wall a foot or so, giving a stoping width up to 6 feet. In general the foot-wall granite shows greater replacement than the hanging-wall.

The ore grade on the 320-fathom level is rather low, but apparently improves in depth. As yet only the upper part of the tin zone has been opened.

370-Fathom Level.—Both foot-wall and hanging-wall are clearly defined. The various alterations of the granite walls and the mineral sequence are similar to those described in the South Crofty lodes. Tourmaline peach is abundant, but is more particularly confined to the tin-bearing zone. Chalco-

pyrite, pyrite, arsenopyrite, and sphalerite are often met with in the lode, particularly along the hanging-wall; they are among the last minerals to be introduced into the lode channel. The richest parts of the lode have a reddish color, imparted by hematite probably resulting from the oxidation of arsenopyrite.

Chlorite is subordinate to the tourmaline, except in the walls, where it occasionally becomes abundant in the capel. Chlorite is said to have been very abundant in the higher old levels.

The tin occurs here also intimately associated with blue tourmaline. Quartz often replaces the tourmaline, growing mainly by force during crystallization. During this process some of the tourmaline was probably taken into solution and recrystallized as rare needles in the quartz. Cassiterite was also slightly replaced by quartz where it occurred as veins in the tourmaline. Besides veining the tourmaline, the cassiterite crystallized in the porous tourmaline mass. Even after the subsequent silicification the tin veins are still preserved, often with a thin facing of tourmaline, separating it from the quartz. On the whole, the quartz in the immediate vicinity of cassiterite is much coarser than that in the tourmaline, as that associated with the tin appears to be mainly "replacing" quartz, while that in the tourmaline is often "grown" quartz.

Apparently at the moment the tin commenced to crystallize, the lode channel contained a good deal of fine, porous, felted tourmaline, in the interstices of which the tin separated out, only slightly replacing tourmaline. Quartz next replaced the tourmaline, but mainly grew by force exerted during crystallization, considerably enlarging the original channel and at the same time reducing bulk for bulk the percentage of original tin and tourmaline.

In addition to the association of cassiterite with tourmaline, it may be said in general that the wider the lode the better the tin values. Where the lode is represented by narrow stringers in capel it is, without exception, poor. The accompaniment of massive peach in a wide part of the lode containing a good deal of white quartz appears favorable; the tin is mainly in the peach.

The lode at one part branches, enclosing a large horse of country for some hundred feet along the strike. The best tin values are at the junction of these branches. Often a higher tin content in a laminated part of the lode is accompanied by a close parallel fracturing in the lode quartz. A fine-grained lode and country-rock does not appear to be a good sign; nor is a hard dense massive lode with practically no jointing—probably an indication of the absence of severe pre-mineral fracturing.

Where the foot-wall is clearly defined, the lode is generally narrow and not accompanied by a rich tin content, and is represented by a siliceous capel between two parallel joints. Pre-mineral shearing had not been extensive and only the more abundant minerals (as quartz) could be deposited.

On the whole, deposition of cassiterite appears to have been favored by a certain relative porosity in the lode at the time the tin was formed. A comparatively medium-grained tourmaline-bearing veinstone appears to carry the best values.

These remarks on tin-value localization may be applied *in toto* to the upper levels examined. Only characters peculiar to those levels will now be discussed.

345-Fathom Level.—The lode shows all the characteristics, mineralogical and structural, already noted on the 370-fathom level. Occasionally it divides into two or more narrow parallel stringers in a hard siliceous capel containing sericite. On this level, there is a peculiar alteration of the granite, in which the whole of the feldspar has been sericitized; occasionally a little gilbertite has been formed. Part of the sericite shows alteration to green chlorite, but a large amount is replaced by an amorphous chlorite, extremely cryptocrystalline, colorless, or very pale yellowish. Small prisms of brown and blue tourmaline occur in the replaced feldspars and evidently felted crystals veined the feldspars. These veins in places form the boundaries to later replacing quartz. The tourmaline veins are cut by later quartz veins, while green chlorite veins the sericite. A little fluorite is

often present associated with gilbertite and probably coming in with the quartz. Some pyrite also accompanied this final phase. A little primary schorl may be detected. Occasionally slight kaolinization has taken place. Generally the original quartz is quite fresh and undisturbed, but there are microscopic bands in which the rock is shattered, having originally broken up into quartz and extremely fine feldspar, which subsequently altered to sericite and a little blue tourmaline. The fine feldspar appears to have been ground into the fractures in the quartz, imparting the appearance of a quartz breccia. Occasionally this feldspar is replaced by a fine felted blue tourmaline in which is often included a little fragmental quartz. The tourmaline is evidently earlier than the sericite. The stages in the alteration of these feldspars are well defined.

In other parts of the lode the feldspars show, besides sericitization, replacement and veining by fine brown tourmaline, and later by the blue variety. Subsequently, quartz replaces the feldspar, veining and replacing the tourmalines also to a certain extent, but generally growing by force during crystallization, although still preserving the original vein-like character of much of the tourmaline.

A little green chlorite is associated with the blue tourmaline. Small grains of tin may be noted as slightly earlier or the same age as the blue tourmaline, but definitely later than the brown variety. This tin is generally included in replaced feldspars, but occasionally in quartz; the tin evidently belongs to the early stages of the blue tourmaline period.

In yet another part of the lode, the secondary quartz replacing the feldspars and veining primary quartz and blue tourmaline is a peculiar microcrystalline to cryptocrystalline variety with an unusual yellowish color due evidently to minute dust-like inclusions. This local variety of quartz was preceded by hematite, which is often moulded on the tourmaline, and it appears probable that the dust inclusions in the quartz may be hematite. This yellowish quartz often crystallizes in optical continuity with the primary coarse-grained quartz.

Occasionally bands of the original granite had been shattered to a fine-grained gouge-like material, the feldspar of which was replaced by fine blue tourmaline and by sericite. Some original quartz fragments in the gouge have been slightly enlarged during subsequent silicification, but often the original border may be noted from the line of sericite and tourmaline inclusions. Some of this secondary quartz has grown by force during crystallization. Another distinctive feature in this particular altered gouge is the fine-grained character of the tin which accompanied the tourmaline and is rather regularly distributed throughout. In places where subsequent silicification has removed most of the tourmaline and sericite, the tin stands out in relief against the colorless quartz.

All these types of veinstones may be noted as final alteration products of the more normal granites which have been previously described as showing greisenization with formation of gilbertite, lepidolite, rubellite, etc.

The sericitization of the granite with subsequent silicification forms the dark capel throughout the length of the level, and has no connection with the tin content. There is no tourmaline peach on either side of the ore shoot, where the lode becomes poor. The leader is either quite thin or non-existent, and the lode channel is represented by a quartz-sericite rock or capel.

Both on this level and on the 370-fathom level the granite country, as the lode is approached along the crosscut, shows definite alteration. Furthest from the lode, the granite is a normal biotite-muscovite granite of white color. Close to the lode (within 20–30 feet) the feldspars become pink or buff colored, tourmaline makes its appearance, and occasionally chlorite, while biotite dies out to a large extent. The whole rock apparently darkens in color.

In the crosscuts on the footwall side of the lode a number of vertical quartz-tourmaline and quartz-chlorite veins are met with up to 6 inches wide. The granite for a distance of 2 to 3 feet on either side of these veins is similar to that near the main lode.

but further away is more normal. In the pink granite near the lode numerous thin ramifying and replacing veins of tourmaline occur with a hardening effect on the rock. They form a vertical fractured zone of granite up to 12 inches wide, the general direction of each vein in the zone being parallel to the whole. They are probably the result of the "vibratory movements" suggested by McAlister.

320-Fathom Level.—At 365 feet west, the lode branches and enrichment again occurs at the junction. The lode is often merely represented by a sheared granite "leader" showing some silicification and chloritization. In this sheared granite there is abundant buff-colored feldspar, primary quartz (enlarged by growth during secondary silicification; secondary quartz is later than the chlorite), gilbertite and a large amount of chlorite. This chlorite, besides being interstitial, occurs as minute ramifying veins in the feldspar, and replaces much of the rock. Associated with this sheared granite there is often a dense black fine-grained tourmaline peach along either wall, while the country generally shows a good deal of chloritization. The values in such a part of the lode are very poor.

Where, however, the feldspars of such a sheared granite are entirely replaced by blue tourmaline and some sericite, leaving only a little primary quartz to indicate the original sheared character of the rock, the tin content is high. In places secondary quartz may still further alter the rock to a quartz-tourmaline material, or even to an almost pure white quartz, but still the tin content may remain high, particularly at the intersection of the lode branches. With this secondary quartz there is often much associated chlorite. The chlorite preceded the quartz, although some continued with the last of the quartz. The chlorite often assumes a relatively coarse micaceous habit, but the later variety is always fine-grained. Within the chlorite the quartz grew by force during crystallization, pushing the chlorite aside, and often showing excellent idiomorphic outlines, so that the chlorite may appear, at a glance, to be interstitial and later. Some of

the quartz may include a little chlorite, owing to the unequal rate of growth at different points on the surface of the growing quartz crystal. In some specimens in which chlorite had veined, sericitized and tourmalinized the feldspars, the later quartz has replaced part of the vein, leaving only small lineally arranged inclusions of chlorite as the continuation of the unreplaced part of the chlorite vein.

One section from this level shows the replacement of sericite by sulphides, and pyrite replacing the center of a quartz crystal from an extremely minute fracture. In another micro-section the tourmalines show unusual zoning. The tourmaline has mainly a pale brownish center with pale blue edges. Some of the tourmaline prisms are a curious dirty blue in the center and brown on the edge. This tourmaline veins the original granite, and later quartz. Replacement by quartz and growth by force during crystallization proceeded together so that the products of both may form one quartz crystal with often a line of tourmaline inclusions to show which part was due to growth and which to replacement. Occasionally where quartz replaces prismatic tourmaline, it retains the tourmaline cross-section at first, but larger crystals gradually enclose them, recrystallization takes place incorporating the small pseudomorphs in the larger quartz, and thus suppressing the original tourmaline outline.

Acknowledgments.—Among those to whom the writer is indebted are Mr. M. T. Taylor of the East Pool Mine, Carn Brea, for his helpful advice on Cornish mining; Mr. Josiah Paull for the courtesy shown him during his stay at the South Crofty Mine, and for the use of plans; Mr. Faull, manager of the Tresavean Mine, for kindly advice and discussion during his investigation of the Tresavean Mine, and also for the ready use of the accompanying mine section; Mr. Davison of the Camborne School of Mines, for the loan of numerous rock sections and literature of Cornish ore deposits; and Dr. J. M. Maclaren for some helpful advice on Cornish geology. For numerous rock sections cut, the writer wishes to express thanks to Mr. Tallin of the Royal School of Mines.

The work was carried out under the immediate supervision of Professor C. G. Cullis, and the writer appreciates the value of his advice and discussion throughout.

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MELBOURNE,
AUSTRALIA.

THE PETROLEUM POSSIBILITIES OF HONDURAS.[1]

ARTHUR H. REDFIELD.

INTRODUCTION.

In the search for oil in Central America, Honduras has by no means escaped attention, for no less than 9 concessions which cover all 17 departments of the Republic, including the Bay Islands, have been taken out. The speculative character of several of these concessions is evidenced by the fact that on four separate occasions concessions were permitted to lapse for non-payment of the guaranty fees; and in several concessions the efforts of the holders have apparently been directed to obtaining extensions of time rather than to actual drilling or to the performance of development work required by the terms of the concession.

It is to be regretted that Honduras has attracted more attention from the concession-hunter than it has from the geologist; for on the basis of its known geology, the number and scope of the concessions obtained is out of proportion to the apparent possibilities of finding petroleum in commercial quantity. Several of the concessions cover Departments of which the underlying formations are prevailingly igneous; in other Departments the sedimentary formations are closely folded, considerably faulted, and largely intruded by late igneous rocks. The object of the present paper is to present a summary of the known data on the geology of Honduras relating to petroleum.

SURFACE FEATURES.

The surface of Honduras is characteristically mountainous. Plains are restricted to the Atlantic and Pacific coastal regions and to the lower courses of certain large rivers. Smaller and widely separated plains occur in the interior of the country as

[1] Published by permission of the Acting Director, U. S. Geological Survey.

broad valley floors, some of which are at considerable elevation above sea-level. The best known of these valley-plains are Sensenti, Otoro, Comayagua, Yugare, Espino, Yoro, Olanchito, Agalta, Catacamas, Danlí, and Paraíso.

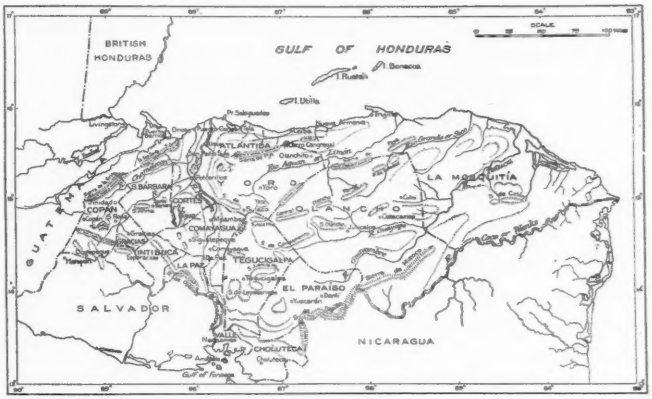

FIG. 67.

The southern half of Honduras back of the narrow Pacific coastal plain bordering the Gulf of Fonseca, is traversed by a cordillera composed of the Tambla, Opatoro, Lepaterique, Dipilto, and Misoco ranges. This cordillera is 50 or 60 miles from the coast and it is irregular and broken, in places curving back into arcs which enclose interior basins or valleys. It presents from the Pacific side the appearance of a great natural wall, ranging from 1,500 to 2,000 meters (4,900 to 6,600 feet) in height, above which tower many volcanic peaks.

In the general mountains of the northern part of the country do not attain the height of those of the southern part. The relief of the Atlantic highlands is quite varied; its culminating points being Omoa Peak (7,000 feet) in the Sierra de Omoa and the Cerro Cangrejal (8,000 feet) in the Sierra de Pija.

The mountains of Honduras are broken in the west by a great transverse structural valley, the Honduras Depression or Plain of

Comayagua, which is 40 miles long, 5 to 15 miles wide, and extends in a north-and-south direction. From this plain the Humuya valley extends northward to the Gulf of Honduras and the Goascorán valley southward to the Pacific Ocean. This depression forms a natural line of comunication between the Atlantic and Pacific coasts of Honduras. East of the Honduras Depression and south of the Sierra de Pija the surface of the country resembles that of a plateau dissected by numerous stream valleys.

AREAL GEOLOGY.

The geology of Honduras is complicated, and the geologic exploration of the territory is far from complete. The journeys of Sapper, made between the years 1898 and 1901 form the basis of most of our present knowledge of the geology of Honduras. Moreover, the greater part of the northern and eastern departments were left unexplored, except for reconnaissances along the river valleys. More recently the researches of Powers and Foye have added to our knowledge of the northern coast and the Gautemalan frontier.

Geologic investigations on the Atlantic coast of Central America are conducted with considerable difficulty owing to the primitive means of transportation, to the thick residual soil, and to the dense tropical vegetation. Rock outcrops occur only in the stream valleys, and few distinctive fossils have been found in the rocks of pre-Tertiary age.

In general, the southern third of Honduras is underlain by post-Tertiary eruptives, by intrusives, and by pre-Cambrian or early Paleozoic crystallines. In the northern two thirds Cretaceous sedimentary rocks crop out in narrow belts, much broken by lava flows, between ranges of older disordered rocks.

Crystalline metamorphic rocks form the cores of the Sierra de la Grita, the Sierra del Espíritu Santo, and the Sierra de Omoa in the northwest part of Honduras. The crystalline rocks of these ranges reappear beyond Puerto Cortés in Punta Salsipuedes and are continued in the islands of Utila, Ruatán, and Bonacca. West of San Pedro Sula a short spur of crystalline rocks, the

Sierra del Palmar, branches off from the main crystalline range.

South of the crystalline Sierra de la Grita extends a parallel range of Lower Cretaceous sedimentary rocks, the Sierra de Merendón. Ancient crystalline rocks form but a minor part of the Merendón range. Farther to the east are the remains of a dissected range of Mesozoic rocks, of which the crest is composed of Middle Cretaceous limestone and the slopes of Metapán (Lower Cretaceous) formations. Late eruptive rocks also form a part of these mountains. Remnants of this dissected Mesozoic range are the Sierra de Colinas, the Sierra de Atima, the Cerros de Santa Bárbara, northwest of Lake Yojoa and the Cerros de Canchia, southeast of Lake Yojoa.

South of the Mesozoic ranges late igneous rocks form the principal cordillera of Honduras, which extends as a continuation of the principal cordillera of southern Guatemala southeastward into Nicaragua. This zone of almost unbroken igneous rocks in the area west of the Honduras Depression extends from 14° 45′ N. southward to the Salvadorean border.

East of the Honduras Depression, the late igneous rocks play a subordinate part, being restricted chiefly to the southwest corner of the region. Older igneous rocks, however, occupy a much larger area, especially in the north, and occurrences of ancient crystalline rocks are more numerous and extensive than in the west.

The Sierra de Pija is composed of ancient crystalline rocks, much intruded, however, by pre-Tertiary igneous rocks. The same rocks are generally present in the Sierra de Paya, which parallels the Pija Range south of Rio Aguan. The Sierra de Soledad, south of the Paya Mountains, consists chiefly of diorite.

The Sierra de Yoro, to the south of the Sierra de Pija, is a range of Lower Cretaceous sedimentary rocks capped by Middle Cretaceous limestone. Little or nothing is known of the eastward extension of this range. Similar Cretaceous rocks compose the Sierra de Esquias to the south.

The Sulaco Mountains are composed in their western portion of ancient crystalline rocks; but in the eastern portion, little is known regarding the ages or relations of the formations.

The crystalline rocks of the Central Olancho Range form perhaps an eastward continuation of the Sulaco Mountains. This range is paralleled on the south by the southern Olancho Range, which is likewise composed of crystalline rocks. The crystalline rocks are continued to the west in the Sierra de Campamento. The Sierra de Comayagua, southeast of Comayagua, may be regarded in turn as a westward continuation of the Sierra de Campamento.

The Sierra de San Juancito represents an outcrop of Triassic sedimentary rocks, much disturbed and metamorphosed, and intruded and capped by eruptive materials.

The Sierra de Dipilto consists principally of old crystalline rocks, which are succeeded on the south by granite. The Sierra de Misoco is composed chiefly of granite. Practically nothing is known of the structure of the Sierra de Colón in the southeast.

The known outcrops of Tertiary sedimentary rocks in the interior of Hunduras are limited to two small areas, one between Ceibita on Rio Ulua and Las Colinas, north of Santa Bárbara, and the other near Tilapa, northeast of Copán. Rocks of Tertiary age have been noted in the narrow Atlantic coastal plain near Puerto Cortés.

Quaternary sediments form the narrow Atlantic coastal plain, and extend for considerable distances up the valleys of Ulua, Aguan, Patuca, and Coco rivers. Alluvium fills the bottoms of the deep interior valleys, and similar material forms the narrow coastal plain on the Pacific coast.

STRATIGRAPHY.

Stratified Rocks.—The oldest rocks in Honduras consist of a crystalline complex, which in its lower portion is gneiss, and in its upper portion chiefly mica-schist and phyllite. In many places the mica-schist grades into micaceous slate (*Thonglimmerschiefer*) and in other localities into hornblende-schist. Intercalations of crystalline limestone are numerous. It is intruded in many places by igneous rocks. A lack of fossils and of detailed knowledge of the crystalline rocks has made it impossible to de-

termine whether they belong to the pre-Cambrian, as supposed by Sapper, or to a later period. The age of part of the metamorphic rocks is now stated by Powers to be Paleozoic, and the age of the remainder is thought to be no older. Carboniferous fossils were found by Powers in altered limestone west of Puerto Barrios, Guatemala, not far from the line of strike of the marble in the Sierra de las Minas, north of Motagua River, in Guatemala. This may throw some light on the age of the crystalline limestone of the older ranges of Honduras.

A series of slate, sericite-schist, and quartzite, quartzitic sandstone, limestone, and quartz-conglomerate which occur in the Dipilto Mountains is regarded by Sapper (28)[1] as Paleozoic. This series rests upon pre-Cambrian (?) crystalline schist, without, however, any apparent conformity. They may even, in the opinion of Sapper (28), form the lower division of the "Tegucigalpa formation" (Triassic). According to Newberry (15) (16), however, limestone said to contain Carboniferous fossils, underlie the Tegucigalpa beds. This corresponds to the structure in Chiapas and Guatemala, where the Todos Santos terrane, believed to be Triassic, rests disconformably on Carboniferous limestone. A series of clay, shale, marl, sandstone, conglomerate, and interbedded limestone, occurring in the Department of Tegucigalpa, has been indentified by Newberry (15) (16) on the basis of its fossil cycads as Rhætic (Upper Triassic). The correctness of this reference has been questioned by Sapper (28), but affirmed by Knowlton[2] and Humphreys (9). Knowlton (10) admits that they are possibly Jurassic. The series attains a thickness of 800 feet. Its petrographic character is varied; the formations are prevailingly red in color. At San Juancito, the Tegucigalpa shale has been altered by pressure and intrusion to hydromica schist.

The occurrence of Jurassic beds in Central America has not been definitely authenticated. A series of clay, marl, sandstone, and conglomerate, with interbedded limestone, correlated by Sap-

[1] See Bibliography at end of paper.

[2] U. S. Geological Survey Professional Paper 71, p. 502, Washington, 1912.

per on the basis of petrographic similarity with the Metapán strata of Guatemala, occurs to a considerable extent in the northern and central parts of Honduras. Fossils obtained by Sapper (28) and identified by Böhm show them to belong to the Lower Cretaceous. The petrographic similarity of the Metapán strata to the Tegucigalpa series (Upper Triassic) has made it difficult to differentiate the two series with any degree of certainty, except where distinctive fossils were available. It is accordingly possible that formations which have been ascribed to the Metapán series may indeed prove on closer study to belong to the Tegucigalpa series.

The Metapán strata are conformably overlain by a moderate thickness of limestone, which in many places in Honduras forms the mountain summits. This limestone near the western boundary of Honduras, near Copán, is characterized by well-preserved specimens of *Rudistes*, and thus may be correlated with the Middle Cretaceous of the Geological Institute of Mexico or the Upper Comanchean of the United States Geological Survey. Crystalline limestone, in which no trace of bedding or fossils have been found, extend from Dos Caminos on the National Railroad to Potrerillos, the railroad terminus. Sapper (28) considered this limestone to be equivalent to that of Copán.

Eocene and Oligocene strata have not been reported as occurring in Honduras. Miocene strata, elsewhere abundant in Central America, are not in evidence here. The Pliocene (?) is represented on the Rio Ulua by sandstone, conglomerate, marl and tuff containing silicified wood near Las Colinas and breccias at Tilapa, northeast of Copán. Marine sandstone and conglomerate of late Tertiary age form cliffs along the shore between Puerto Cortés and Omoa. The sandstone of this series is greenish-gray when fresh, but oxidizes to a limonitic clay. It is composed of very fine grains of quartz and muscovite and of about an equal amount of glauconite particles. The rock is gritty and friable and hence both in color and texture a typical greensand.

Gently folded Tertiary or possibly early Pleistocene sand, sandstone, gravel, and clay are exposed in sea cliffs 40 feet in height between Tulián, south of Puerto Cortés, and Omoa. Bedding in

these sediments is on the whole regular, but within individual strata there is cross-bedding. The gravel is composed in part of boulders, 3 inches to a foot in diameter, packed together in a way to suggest deposition in streams and not in the sea. These beds show a marked similarity to those at Livingston, Guatemala.

Igneous Rocks.—Outcrops of granite are fairly numerous in Honduras. Sapper (28) places the age of the Honduras granite as pre-Mesozoic, as it was nowhere seen to penetrate the Triassic or Cretaceous sedimentary rocks. He believes the principal intrusions of granite in the adjacent Republic of Guatemala to have occurred at the close of the Carboniferous.

Powers (21) and Foye(6) note the widespread occurrence of granodiorite intruded into the schist and quartzite of the Sierra de Pija. According to Sapper (28), hornblende-granite or quartz-diorite occurs extensively in the Atlantic coastal ranges of Honduras and in Olancho. Exposures of diorite are widespread in the Sierra de Omoa and in the Atlantic coastal ranges, and in isolated zones in the Departments of Olancho and El Paraíso. A similar tonalite crops out in Ulua River and in the hills near Uraca. Pebbles of gabbro occur in small streams flowing from the Sierra de Omoa. Foye (6) reports the occurrence of gabbro in the hills west of Micos Lagoon.

Powers (21) suggests that the granodiorite, diorite, and tonalite of the Pija Mountains may represent phases of a single large batholith. These plutonic rocks are confined to the areas of the crystalline complex of pre-Cambrian (?) or undetermined Paleozoic age. If, as Powers (21) thinks, the metamorphic rocks of the Sierra de Pija are of Paleozoic age, the batholithic intrusion probably occurred during the folding which is assumed to have occurred at the close of the Paleozoic.

Serpentine, which occurs extensively in Guatemala, is known to occur in Honduras only on the Island of Bonacca and at the northern foot of the Sierra de Omoa. Sapper (27) refers the serpentine of Chiapas and northern Guatemala, to the interval between the Carboniferous and the Cretaceous. Foye (6) reports the occurrence, in the Pija Mountains of metamorphosed

igneous rocks, among which are dioritic orthogneiss, actinolite gneiss, hornblende, and biotite schist.

Diabase occurs in the Atlantic coastal range between Medina and La Ceiba, as well as in several places in the Departments of Comayagua, El Paraíso, and Olancho, and in the Department of Copán near the Guatemalan frontier. The exact age of the diabase is difficult to determine. It is extensively intruded into the Cretaceous strata of Honduras, and according to Sapper (27) a similar diabase is intruded into the Tertiary of Alta Verapaz, Guatemala.

Exposures of Tertiary and post-Tertiary igneous rocks are numerous. In southwestern Honduras, they form the mountain ranges. In the Departments of Olancho and Santa Bárbara sheets of lava and tuff cover considerable areas, and numerous dikes cut the Cretaceous sedimentary strata. In the Sierra de Pija diabase and porphyrite conceal in places the underlying older plutonic rocks. The extrusion of the andesite, and of basalt, began, according to Sapper (27), in the Middle Tertiary, and has continued into the Recent. Olivine basalt ocurs in the Sierra de Pija, in the Sierra de Omoa at Chameleoncito, near Puerto Cortés, and on the Utilla Island. In the opinion of Powers (21), a late, perhaps Pleistocene age must be assigned to these flows.

TECTONICS.

General Statement.—A system of mountains composed of folded rocks striking east-and-west appears to have existed in Honduras and northern Nicaragua in pre-Cambrian or at least in early Paleozoic time. Only the southern part of Honduras shared in the transgression of the Carboniferous seas. The end of Paleozoic time was marked by elevation, diastrophism and igneous intrusion.

Land conditions prevailed in Honduras, as over most of the North American continent during the Triassic period. In the Rhætic epoch continental deposits were laid down in small basins, notably in the vicinity of Tegucigalpa. There is no evidence of submergence in Jurassic time. The principal submergence of

Honduran territory since the pre-Cambrian or early Paleozoic took place in Comanchean time, when the basins lying between older crystalline ranges received deposits of marine sand and clay, and later of limestone. Emergence began in the Upper Cretaceous.

During most of the Tertiary Honduras remained above sea-level. Zoogeographic evidence suggests, according to Vaughan (33) (34), the existence of a land-bridge between Honduras and Jamaica during late Miocene or Pliocene time. The time and the manner in which the separation took place is not definitely known. The Pliocene formations of small extent in the northwest are apparently of continental origin, as are the tuffs of Tilapa. Sedimentation occurred in the Pliocene (?) and Pleistocene only along the Caribbean coast. In the Quaternary alluviation took place along the Caribbean coast, on the river flood-plains, and in interior basins.

Diastrophism.—According to Sapper (26), three principal periods of diastrophism have evidently occurred in Central America: (1) at or before the close of the pre-Cambrian; (2) at the close of the Paleozoic; (3) late in or at the close of the Miocene. To these Powers (21) adds a fourth, late in or after the Pliocene. The late Paleozoic folding, which was more intense toward the south, developed the Cordilleran axes. The Miocene movements, though less intense, developed the parallel ranges of the Caribbean system, and initiated the cycle of erosion in which the present mountains were shaped. The late Pliocene or post-Pliocene moveents were evidently both vertical and tangential as shown by the position of Pliocene and Pleistocene (?) sediments from Yucatan southward through Honduras. The effects of tangential movements are especially notable in the recent sediments of the Atlantic Coast region near Puerto Cortés and Omoa, Honduras, and Lake Izabal, Guatemala.

The prevailing direction of disturbance in Central America, as evidenced in both lines of folding and of faulting, is generally east-and-west (the "Central American strike" according to Sapper). In a few unimportant cases a north-south direction of

strike ("Andine strike," according to Hershey) has been observed, notably by Hershey [3] on the Azuero Peninsula of Panama and by Mierisch [4] in northeastern Nicaragua. A north-south strike is also apparent in northern Nicaragua and in Honduras on both sides of the great "Honduras Depression," which extends from Puerto Cortés to the Gulf of Fonseca. This depression, in the opinion of Sapper (25) (27), may be ascribed to local transverse folding or to an independent transverse dislocation rather than to the intersection of a new line of mountain folding. There are indications that would suggest that is a "graben," between cross fractures.

The tectonic lines of Central America do not trend in a true east-west direction, but form broad curves, convex toward the south. The mountain ranges which have the characteristic "Central American strike" are divided into two separate but parallel systems, a northern or "Guatemalan" system and a southern or "Costa Rican" system, which diverge from one another because of the differences in their radii of curvature. They are connected, however, by the transverse highland of central Nicaragua, which consists of late eruptives and tuffs.

The northern or "Guatemalan" system, to which the mountains of Honduras belong, has considerably greater extent than the southern or "Costa Rican" system, both in length and breadth. The "Guatemalan system" consists of two flat arcs, separated by the Honduras Depression, of which the geometric centers lie respectively north of Yucatan and in the Gulf of Mexico north of the Straits of Yucatan.

The pre-Cambrian (?) or Paleozoic crystalline mountain range of Guatemala, which is itself a continuation of the crystalline Sierra Cimaltepec of Oaxaca, shows a double curve as it extends through the frontier ranges of northwestern Honduras and ends in the Bay islands. The crystalline ranges east of the Honduras Depression show a curvature in general so flat as to be almost

[3] Hershey, O. H., Geology of the central portion of the Isthmus of Panama: Bull. Dept. Geol. Univ. Calif., vol. 2, no. 8, pp. 231–267, Berkeley, 1902.

[4] Mierisch, B., Eine Reise querdurch Nicaragua: Petermanns Mitteil., vol. 41, pp. 61–62, Gotha, 1895.

rectilinear. The cleavage of the schist and slate of the Sierra de Pija south of La Ceiba strikes about N. 60° E., parallel to the range. The folding of the rocks of the crystalline range is assumed to have occurred in pre-Cambrian or early Paleozoic time. The trend of the Sierra de Dipilto which is ascribed by Powers (21) to late Carboniferous folding, is almost N. 50° E.

VULCANISM.

The four principal periods of diastrophism may have been also the chief periods of volcanic action. Vulcanism undoubtedly began in the central portion of Central America before the Miocene deformation, as the earlier volcanic rocks are steeply folded.

The alignment and order of the Pleistocene volcanoes of the Pacific Coast (represented in Honduras by the islands of the Gulf of Fonseca) indicate the existence of lines of disturbance of a special character, which are independent of the Central American trend. The most important volcanoes of the northern half of Central America (Guatemala to Nicaragua) are arranged in a few almost parallel lines, which trend generally WNW–ESE. From these longitudinal lines of vulcanism several short transverse lines branch off. The main lines, which converge irregularly, appear to indicate the course of faults which were formed by the subsidence of the Pacific Ocean basin. They lie in general south of almost parallel ranges of late igneous rocks which probably owe their origin to a similar, but earlier and more intensively active cause.

INDICATIONS OF OIL.

Seepages of petroleum are reported at Guare, 66 miles south of Puerto Cortés, in the Guare Mountains, 21 miles north of Comayagua, in a bituminous limestone, presumbly of Neocomian (Lower Cretaceous) age. The oil-bearing rock outcrops for two miles in a gulch. It contains numerous pockets of paraffine-base petroleum. According to Gen. Marín, there are also strata impregnated with ozokerite. The limestone is overlain by a red clay-shale and the shale by limestone.

Other indications are said to occur along Rio Aguan and at various points not specified on the Caribbean coastal plain. Gas seepages are also reported, and an oil scum is said to be visible beyond the surf line. An oily scum believed to be petroleum, is reported to cover Mico Lagoon near Tela. These occurrences have not been authenticated.

A carbonaceous limestone is said to crop out on Patuca River in the District of Mosquitia.

A remarkably pure asphalt is reported to occur near Juticalpa, in the Department of Olancho. This is probably identical with the gilsonite deposit on the right bank of Rio Pinal, a tributary of Rio Guayape, reported in 1912 by Consul A. T. Haeberle (8). The gilsonite occurs in a horizontal reef, about 12 feet thick. The reef consists of a number of veins, 2 to 8 inches in thickness, separated by partings of sanstone. There are also a few vertical veins, about 3 inches in width. These cross Rio Pinal, but it is not known whether they continue on the opposite bank. The gilsonite veins occur probably in the Metapán strata, of which Sapper (28) maps an outcrop in the middle of the valley of Rio Guayape.

POSSIBILITIES OF OIL.

No productive oil sands have thus far been discovered in Mexico or Central America in strata older than the Cretaceous. The best authenticated petroleum seepages noted in Honduras, those of Guare, occur in the Metapán strata (Lower Cretaceous). The gilsonite veins of Rio Pinal, in Olancho, may apparently be referred to the Metapán strata.

Exposures of the Metapán strata occur, as has been stated before, in narrow zones, apparently much folded and faulted, and intruded to a considerable extent by igneous rocks. No extensive areas underlain by Cretaceous or younger sediments that have not been intruded by post-Tertiary effusives are at present known.

Before any final judgment can be safely pronounced on the possibility of obtaining oil in commercial quantity from Honduras, considerably more will have to be known of the local

geology of the country. If favorable structures can be found in the Metapán strata, local pools of limited extent may occur. Anticlinal structures are indicated in only a few places in the geologic cross-sections made by Sapper. Terraced or fault-sealed monoclines or intruded structures similar to those of the Panuco district of Mexico may indeed occur; but no information of such occurrences is at hand.

The Territory of La Mosquitía has been credited by rumor with having exceptional petroleum possibilities. This Territory is almost unknown both geographically and geologically. The reconnaissances made by Sapper along the valleys of Rio Sico and Rio Coco would indicate, however, that it does not differ in its main geologic features from the other departments of northern Honduras. The Lower and Middle Cretaceous sedimentary rocks occur only in narrow bands, considerably faulted and intruded by igneous rocks. On the basis of our present information, no more favorable judgment may be pronounced on the Territory of La Mosquitía than on the other departments of northern Honduras.

LEGISLATION.

Mines in Honduras, even though situated on private property, belong to the nation, but may be claimed ("denounced") by individuals for exploitation under certain conditions. Prospecting on unfenced or uncultivated lands is free; otherwise a license must be obtained.

No discrimination exists in law between the rights of citizens and those of aliens to acquire or operate mineral properties, to distribute mineral products, or to sell or transfer mining rights.

CONCESSIONS.

The only exclusive concession granted by the Congress of Honduras was awarded in 1912, to General Calixto Marín and seventeen other Honduran citizens. The concession covered originally the Department of Comayagua, but was later made to include those of Atlántida, Yoro, and Cortés as well, making a total area of over 8,100 square miles. Their rights in the Departments of

Atlántida, Yoro, and Cortés, covering about 6,600 square miles were later transferred to the Honduras Petroleum Company, Inc., of which Don Augustín Disdier, of Ceiba, was president, and Mr. Irving S. Josephs, of Chicago, manager. The Comayagua concession was retained by General Marín, who organized in Honduras a company to develop it. Late in 1919 the Honduras Trust Ltd., was organized in London with a view to acquiring from the Honduras Petroleum Company that part of the Marín concession which covered the Departments of Yoro, Cortés, and Atlántida. Upon an unfavorable report by Messrs. A. Beeby Thompson and partners, the directors of the company decided to abandon the purchase of the necessary shares in the Honduras Petroleum Company.

The Marín concession runs for 50 years from February 22, 1913. Its terms give the holders the right to extract and refine petroleum and naptha within the State. The concessionaires may import necessary supplies free of duty, lay pipe-lines, use timber and water on Government lands for generating power, and may expropriate private lands on paying adequate compensation. The Government is to receive 10 per cent. of all oil extracted, or its value, and 10 per cent. of all coal found. Natural gas or water found becomes the property of the concessionnaires. The concessionnaires must rebuild old highways and construct certain new ones, notably a high road from Lake Yojoa to Siguatepeque. A tax of 1,000 pesos (about $500) must be paid annually for the first 5 years; 2,000 gold pesos ($1,000) annually for the next fifteen years; and thereafter 3,000 silver pesos ($1,500) annually.

The concession was modified in 1913 and 1914, and was voided in 1919 because the concessionnaire did not complete a road from Siguatepeque to Lake Yojoa, according to the terms of the contract. It was extended, however, despite the protests of other concession-seekers and is still valid.

A number of other concessions, which are in reality merely drilling permits, have been granted to cover the remaining Departments of Honduras. No concessionnaire has any exclusive privileges except that the drilling operations of any concession-

naire are protected in the event that oil is discovered, and an exclusive zone of about 3,500 acres will be assigned to any successful well. The term of these concessions is uniformly 25 years.

The first of these non-exclusive concessions was granted in 1919 to José Antonio Rivas and three other Honduran citizens, covering the Departments of Colón, Olancho, and El Paraíso, and the Territory of La Mosquitia. A second, granted to Tomás Becerra B. and three others covers the Departments of Choluteca, Valle, Intibucá, Tegucigalpa, and La Paz. Both of these concessions were voided later in 1919 for non-payment of certain fees, and renewed on January 9, 1921, to Mr. Russel Palmer. Two other concessions of the same type, granted to Mr. James Henderson and to Don Gregorio Lobo and associates, were considered lapsed and have not been renewed.

A third concession was granted in 1920, to Carlos Gutiérrez, Jr. It covers the Departments of El Paraíso, Santa Bárbara, Intibucá, La Paz, Colón, Olancho, and Choluteca, and the Territory of La Mosquitia. The Gutiérrez concession was transferred in 1920 to Mr. Duncan Elliott Alves, of London, representing the British Controlled Oilfields, Ltd.

A non-exclusive concession granted to Mr. Irving S. Josephs of Chicago for 25 years from March 25, 1920, covers the Department of Colón. One of the obligations of the permit is to construct a school for advanced education in the Department of Colón.

A 25-year concession conferring non-exclusive rights in all Departments of Honduras except of Comayagua, Yoro, Cortés, and Atlántida was granted in 1920, and later transferred to Mr. Frederick George Watson, of London, who represented the Anglo-Persian Oil Co., Ltd.

A concession to prospect the Departments of Santa Bárbara, Copán, Gracias, and Ocotepeque was granted early in 1921 by the Congress to Eusebio Toledo, Joaquín Medina Planas, and associates. Its terms are similar to those previously described.

DIFFICULTIES OF DEVELOPMENT.

The severest problem to be encountered in developing any petroleum resources that may exist in Honduras is that of transportation. This is for the most part of a primitive type, although recently, improvements have been made. Railroads in Honduras consist of short, disconnected lines, built for the most part to serve the needs of the banana and lumber industries.

Roads are few and over the greater part of Honduras, communication is by rough bridle-paths. The cost of bringing drilling equipment or other heavy machinery over rough mountain trails is almost prohibitive.

The supply of labor is not plentiful. The density of population in Honduras does not exceed 14 to the square mile. The New York and Honduras Rosario Company is said to have had difficulty in obtaining sufficient labor for its silver mine near San Juancito. Drillers and skilled employees must be brought in from outside.

The water supply is generally insufficient. The streams of Honduras are for the most part mere trickles in the dry season, and raging torrents in the wet season. To secure an equable supply of water would entail building costly dams or reservoirs.

Fuel is scarce. Though coal beds are reported in the districts of Tegucigalpa, El Paraíso, Yoro, Gracias, and El Valle, none is mined. Coal is imported from the United States, almost entirely for the use of the railroads. Imports of coal into Honduras from 1913 to 1920 have averaged about 14,000 long tons a year.

RESULTS OF PROSPECTING.

The Honduras Petroleum Company had in 1920 two drilling outfits at work near Omoa. Gas was said to have been encountered; but no find of oil was reported.

Drilling was begun in April, 1921, by the Anglo-Persian Company, under the Strabolgi concession, in the suburb of Calona, municipality of Juticalpa, Department of Olancho, in compliance with the terms of the concession. No report of the results of the drilling has been made public.

In August, 1922, the Honduras Petroleum Company was reported to have closed its office in Tegucigalpa and to have withdrawn from its explorations, as its several test wells proved to be dry. The concession is said to have been surrendered.

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OCCURRENCES OF LADDER VEINS IN MINNESOTA.[1]

FRANK F. GROUT.

OCCURRENCE.

Ladder veins are found at many places in northern Minnesota. Most of them are related genetically to the pegmatites of a granite batholith occupying the northern part of St. Louis County, Minnesota, but one is a rhyolitic dike near Eveleth on the Mesabi range.

The batholith is limited on the north by older schists and gneisses on Kabetogama, Namekan, and Sand Point lakes; on the south by the formations of the Vermilion Iron Range and their westward extension. The western boundary of the batholith is drift covered and not located with accuracy, but the granite seems to extend only a short distance beyond the boundaries of St. Louis County. Eastward the mass extends into Canada, and has not been followed. The total area of the granite, and therefore the range of the related ladder veins, is about 40 by 80 miles.

Some areas near the center of this batholith seem to have been eroded to such a depth that fresh granite with little variation is now exposed. Over a much wider area around this massive granite the exposures are confused by inclusions, roof pendants, pegmatitic and aplitic dikes, and segregations; in short, all the complexity characteristic of the roof phase of a batholith.

The pegmatitic dikes in a few small areas contain enough coarse magnetite to arouse considerable interest in the material as a prospective iron ore. This has justified more detailed mapping than was formerly done and led to the discovery of a relationship between the good magnetite areas and the ladder veins. Only a small proportion of the total number of pegmatite dikes contain

[1] Published by permission of the Director of the Minnesota Geological Survey. Presented at the Ann Arbor Meeting, Society of Economic Geologists, December, 1922.

magnetite; and, similarly, only a small proportion have ladder veins. These minor features, however, show their relationship in the fact that three of the four best magnetite districts show abundant ladder veins, and very few ladder veins are found in pegmatites that do not contain magnetite.

The granite is a normal medium-grained granite, usually pink from microcline, with somewhat less orthoclase, albite, and quartz, and a very small amount of biotite.

The most abundant contact rocks are biotite schists in considerable variety, showing sedimentary bedding that in many places crosses the schistosity. There are also some areas of hornblende schist and older granite gneisses, but these are wholly subordinate—probably less than 5 per cent. of the material which antedates the granite.

It is believed, for reasons to be presented elsewhere, that the mica schist is the altered equivalent of Lower-Middle Huronian slates. If so, the granite and ladder veins here described are of Algomian age.

Easily accessible locations for inspection of ladder veins are: 300 paces northeast of the station (end of siding) at Kinmount on the Duluth, Winnipeg and Pacific Railway; and in the bluff a mile west of the "half-way house" at Buyck, reached by automobile from the railway station at Orr. The exceptional case of granite with ladder veins was seen only in the N.W. ¼ of section 13, T. 68 N., R. 18 W. The rhyolite porphyry dike with ladder veins was found by Dr. John W. Gruner in the S.E. ¼ of section 29, T. 58 N., R. 17 W.

DESCRIPTION.

The pegmatites of the area as a whole show considerable variety. Through most of the area the schist is much disturbed, and the pegmatites wind in and out among fragments. Furthermore the pegmatites and granite probably intruded the schists in a series of successive events, so that the present rock shows a complex network of crossing structures. Along Kabetogama Lake on the north, there are large muscovite pegmatite dikes that generally follow the schistosity of the region.

The ladder veins are apparently developed only in the latest of the series of pegmatites. These may follow the structure of schist fragments or cross the structure at high angles. In a large way the pegmatite may be likened to the matrix of a schist breccia. The late pegmatites are commonly a conspicuous light pink in color, crossing pinkish white or brownish white granite, and dark brownish gray schist. These pegmatites contain chiefly pink microcline or graphic granite, a little white albite and gray quartz. Biotite is not always present, but is far more common than any other dark mineral. Magnetite, garnet, and tourmaline may be seen in a number of places. The size of grain varies from medium granitoid in some of the smaller dikes to coarsely pegmatitic, the coarser masses being usually of variable grain.

A few of these latest pegmatites show ladder veins of quartz that has the same color and general character as the quartz grains in the pegmatites. So far the structure has been noted only in the case of dike-like pegmatites (as distinct from bunches or segregations). The walls are more frequently schist than granite, but the two rocks are commonly mixed by the injection of the schist lit-par-lit. The structures are best appreciated by a glance at Fig. 68. The black represents massive quartz. No vugs or comb structures have been seen in the quartz. The quartz veins extend in most cases (though not all), to the edge of the pegmatite. The openings in which the quartz was deposited have in no case been found to pass into the schist. There have been seen, however, a few veins of similar massive gray quartz in the neighborhood of the ladder veins; some as much as 30 feet long, and crossing all the rocks—schist, granite, and pegmatite—without evident change. It is uncertain if they have any relation to the ladders here described. No mineral but quartz has been seen in the ladder veins unless a little muscovite along the border of one may prove to be related to the ladder rather than the pegmatite.

In one exceptional case the ladder vein structure appeared in a granite dike or sill so fine grained that it is not properly classed as pegmatite, Fig, 68, *E*. Since it differs in some other

AUG 2

respects from those in pegmatite, it is entitled to separate classification.

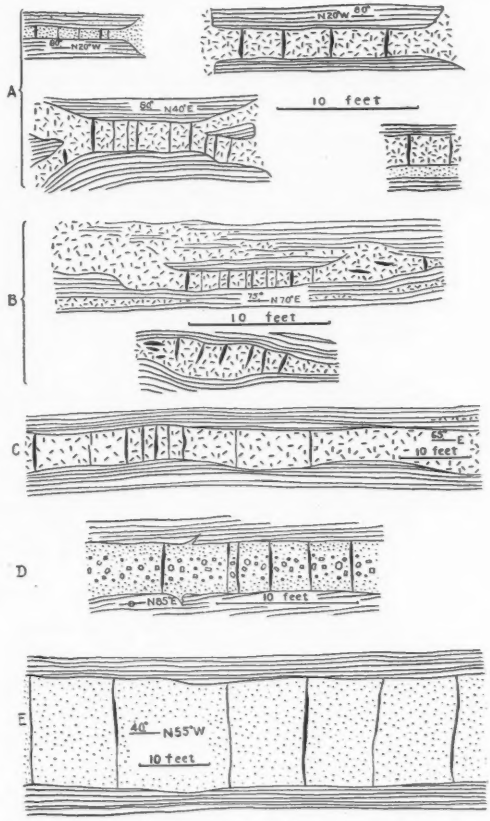

FIG. 68.

In the rhyolite porphyry dike near Eveleth, ladder veins of quartz show similar structures. (See Fig. 68, *D*). Here some of the veins cross the contact and extend a few inches across the schistosity into the graywacke-schist walls. Other quartz

veins in the schist follow the structure of the schist. The dike is believed by Dr. Gruner to be of more recent date than the Giants Range granite; it crosses the Lower-Middle Huronian schists and is not altered as might be expected if it antedated the granite.

The steps in all the ladders tend generally to lie in parallel sheets roughly at right angles to the planes of the dikes. None were exposed well enough to give a clear proof of their position in three dimensions, but some were beveled more steeply than others and the extension of the ladder down the dip of the dikes is clear.

In several pegmatites there are not only cross veins making a ladder, but some irregular stringers of quartz more nearly longitudinal. These when centrally placed suggest that the ladder quartz may have formed much as the central quartzose differentiate of a pegmatite often forms. Such dikes with differentiated quartz centers are not uncommon in the region, but the actual gradation from a central quartz band to a ladder vein has not been seen.

In detail, each step of the ladder, though roughly a tabular mass, shows a much greater thickness in the middle of the dike than at the sides. The exposure of the truncated surface is like the cross section of a lens, doubly convex.

MEASUREMENTS.

Measurements were made of several of the ladder veins to supplement the sketches which are on such a scale that they can hardly show accurately the width of the very narrow veins. As an example, the following data are from a line down the center of the main part of dike sketched in Fig. 68, *B;* the center showing the maximum width of quartz in the ladder. From left to right there are:

Pegmatite at end
3/8 inch quartz
8 inches pegmatite
1/8 inch quartz
11 inches pegmatite
1/8 inch quartz
6 inches pegmatite
1/4 inch quartz
10 inches pegmatite
3/16 inch quartz
4 inches pegmatite
1/8 in quartz
11 inches pegmatite
1/4 inch quartz
6 1/2 inches pegmatite
1/8 inch quartz
10 inches pegmatite
1/4 inch quartz
15 inches pegmatite
1/8 inch quartz
24 inches pegmatite with horizontal segregations of quartz
1/2 inch quartz

Total: 2 1/16 inches quartz and about 100 inches pegmatite.

The dike near Ash River Falls gave the following data down the center of the dike, from left to right (Fig. 68, *A*).

Pegmatite on the southwest branch
1/2 inch quartz
12 inches pegmatite
1 1/4 inches quartz
16 inches pegmatite
1/2 inch quartz
16 inches pegmatite
1/2 inch quartz
11 inches pegmatite
1 1/4 inches quartz
35 inches pegmatite
1 inch quartz
34 inches pegmatite
3/4 inch quartz in southeast branch
4 inches pegmatite in southeast branch
1/4 inch quartz in southeast branch
13 inches pegmatite in southeast branch
3/4 inch quartz in southeast branch
Pegmatite concealed after 4 inches

Total: 6 3/4 inches quartz and about 145 inches pegmatite.

In the first example about 2 per cent. and in the second about 4.5 per cent. of a section along the center of the dike is occupied by quartz in ladder veins. The range in nine pegmatite dikes

with quartz ladder veins is from 1.5 per cent. to 4.5 per cent., and the average is roughly 2.5 per cent.

In contrast with these the granite sill shown in Fig. 68, *E*, has about 0.5 per cent. of quartz in ladder veins down the center of the sill.

The rhyolite porphyry dike of the Mesabi range is reported by Dr. Gruner to have approximately 2 per cent. of its central length occupied by quartz.

LADDER VEINS IN OTHER PLACES.

Ladder veins are reported from a few other districts, Thelemarken, Norway; Coeur d'Alene, Idaho; and several districts in Australia; (the suggestion that the quartz reefs in Berezov and Pyšminsk, districts of the Ural Mountains are ladder veins[2] is denied by Purington who calls attention to the fact that the reefs are simply wide parts of veins that extend continuously through several formations).[3]

In Thelemarken several granite dikes have ladder veins with quartz and copper ores, and a local alteration of granite to greisen near the ore.[4]

In the Standard-Mammoth Lode in the Coeur d'Alenes, a vein of siderite, galena, etc., in quartzite walls has a ladder vein of quartz. The quartz here adds no metal to the ore, but rather decreases its value. The cross veins extend in a few cases into the quartzite, but only for a short distance and with much reduced size.[5]

In New South Wales, molybdenite quartz ladder veins cross a pegmatite dike with relations very much like these in Minnesota.

[2] Pošepny, F., "Die Golddistricte von Berezov und Mias am Ural," *Archiv. für Prakt. Geol.*, II. pp. 547–9 (1895), and "Genesis of Ore Deposits," *Trans. A. I. M. E.*, vol. 23, p. 266 (1893). Karpinsky, A., Guide, seventh inter. geol. Congress, 1897, vol. V., pp. 41–2.

[3] Purington, C. W., "Observations on Gold Deposits," *Eng. and Min. Jour.*, vol. 75, June, 1903, p. 893.

[4] Vogt, J. H. L., "Zur classification der Erzvorkommen," *Zeit. f. Prakt. Geol.*, April, 1895, pp. 149–150.

[5] Ransome, F. L., "Geology and Ore Deposits of the Coeur d'Alene District, Idaho," U. S. Geol. Survey, Prof. Paper 62, p. 128, 1908.

Andrews[6] attributes the openings to the cooling of the dike and suggests that the ladder vein filling is derived from the consolidated but still hot granite walls.

In Victoria, ladder veins are described from several places, notably the Morning Star, at Woods Point, and the Waverly mine. In these, the ladder veins are gold-bearing quartz crossing dikes of igneous rocks—granite, diorite, "greenstone," and lamprophyre—most commonly where the dike is unusually thick. The ladder veins are not all in strictly parallel sheets, but all run transversely in the dikes and have no connection with each other. They do not extend across adjoining formations, and rarely extend any great distance beyond the walls of the dikes. The ladder veins range from an inch to several feet in thickness, but no accurate data are available as to the proportion of igneous material to vein matter.[7] The exploration of the Morning Star dike, however, has extended to a depth of 700 feet and crossed at least 12 reefs, one of which is said to be 20 feet thick. The openings filled by quartz reefs must have been 2 or 3 per cent. of the volume of the dike. Whitelaw's photographs confirm this conclusion.[8]

Herman says that the A 1 deposit, while showing the structure of the ladder veins, is a silicified sedimentary rock between two dikes, and not in the dikes themselves.[9]

A similar set of quartz-gold reefs cross a steeply tilted 30-foot bed of dark slate in the Bendigo gold field. One wall of the slate is a graphitic clay and the other a hard sandstone. The ladder veins—"floors"—of quartz penetrate only short distances into the sandstone and none of them pass into the clay wall.[10]

[6] Andrews, E. C., "The Molybdenum Industry in New South Wales," N. S. Wales Geological Survey, Mineral Resources No. 24, p. 53 (1916).

[7] Phillips-Louis, "A Treatise on Ore Deposits," 2d edition, 1896, pp. 635–6. Herman, H., "Economic Geology and Mineral Resources of Victoria," Geol. Survey of Victoria Bull. 34 (1914). Junner, N. R., "Gold Occurrences of Victoria, Australia," ECON. GEOL., vol. 16, pp. 92–94 (1921). Whitelaw, O. A. L., "The Woods Point Gold Fields," Mem. Geol. Survey of Victoria, No. 3, p. 11, 1905.

[8] *Op. cit.*, Plate XVI.–*B*.

[9] *Op. cit.*, p. 27.

[10] Phillips-Louis, *op. cit.*, p. 637.

DEFINITIONS OF LADDER VEIN.

Beck,[11] Lindgren,[12] and Vogt[13] define ladder veins in terms of "eruptive" or "intrusive" rocks or "granite dikes," but the occurrence of exactly similar structures in a vein in Idaho, and in sediments in Victoria, make it desirable to broaden the definition so as to include both. Possibly the pegmatites here described may emphasize the relation by constituting an intermediate case, or connecting link between dikes and veins. The definition given by Emmons is broad enough to cover all these cases:[14] A ladder vein is a fractured zone in which there are more or less parallel cross fractures more or less regularly spaced.

ORIGIN OF LADDER VEINS.

The series of cross fractures in a tabular mass of mineral matter may develop in two distinct ways; first by the shrinkage of the mass, and second by a movement of the walls.

The contraction theory has been advocated by those who limit their idea of ladder veins to occurrences in igneous dikes, the cooling being supposed to result in the necessary contraction. Thus Junner, Whitelaw, Andrews, Beck, Lindgren, and Pošepny in the papers already cited, refer to contraction or cooling as the probable cause of fissures, or classify the ladder veins under the head of contraction or cooling fissures.

The contraction theory can hardly be applied to a ladder vein in slate with sedimentary beds both above and below it, as at Bendigo; nor to a common mineral vein with ladder veins crossing it. Ransome[15] says the Coeur d'Alene veins "appear to have resulted from local tension along the lode produced by some comparatively recent slight tangential movement of the walls and ore." No considerable movement, however, has occurred since the ladder veins were filled.

[11] Beck, Richard (Weed, W. H.), "The Nature of Ore Deposits," 1st edition, p. 164, 1909.

[12] Lindgren, W., "Mineral Deposits," 2d edition, p. 154, 1919.

[13] Vogt, J. H. L., *op. cit.*, p. 149.

[14] Emmons, W. H., "Principles of Economic Geology," 1st edition, p. 187, 1918.

[15] *Op. cit.*, p. 128.

The measurements given above for the ladder veins of Minnesota show about 2½ per cent. of quartz along the center of the dikes. Since the ladder veins decrease to zero at the borders of the dikes, the volume of the ladder vein may be estimated as between one and two per cent. of the volume of the dike. This is somewhat greater than the shrinkage expected in a granite upon cooling from 800° C. to ordinary temperatures.[16] Furthermore the openings would result from a differential shrinkage —a difference in the shrinkage of a dike and its walls—and it may be assumed that when the dike was intruded the walls were much warmer than "ordinary temperatures." It therefore appears unlikely that cooling contraction accounts for most of the ladder veins.

Additional evidence is given by a comparison of the ladder veins of the granite and those of the pegmatite. The ladder vein in granite is about 0.5 per cent. of the central length of the dike; those in pegmatite are about 2.5 per cent. of the central length of the pegmatites. Now it is commonly assumed that granite was hotter when it solidified than pegmatite and would be likely to shrink more. To explain the difference in the two cases, it might be suggested that the pegmatite was hotter than the granite; or that the granite and its walls were more nearly the same temperature than the pegmatite and its walls; but either suggestion seems improbable.

Still the suggestion of shrinkage is not an impossible one. Two explanations may be offered for the large openings. (1) The quartz veins of the ladder seem to be such as normally deposit from water, and pegmatite is a hydrous magma. It may be that the greater amount of opening in the pegmatite is due to the greater amount of water escaping from the crystallizing magma. There is little available evidence for or against this hypothesis. The characteristic association of the ladder veins and magnetite bearing phases of pegmatite suggests that hydrous magmas were involved; and seems to relate the

[16] Merrill, G. P., "Stones for Building and Decoration," pp. 422–3 (1910), gives .000004825 inches expansion per inch per degree Fahrenheit. Emmons, W. H., calculated for Chamberlin and Salisbury, "Geology," vol. 1, 2d ed., p. 573, 1909.

veins to some inherent quality of magma rather than later metamorphism. (2) It is evident from the sketches that some of the ladder veins are limited to the narrow portions of the dikes. Possibly the shrinkage of the wider ends was taken up by movements in the narrower parts of the dike.

Probably the strongest argument for shrinkage is the lenticular cross section of the openings, which would be much more likely from shrinkage than from any other sort of tension.

The final explanation, that of movements of the walls, is free from the objection raised by the large percentage of opening. Tangential movements of the walls of a brittle rock might, by tension, open up cross fractures nearly at right angles to the plane of the tabular mass. The amount of opening would then vary with the amount of movement. It is difficult, however, to see why such openings should be so much wider in the center of the dike than at the sides.

SUMMARY.

In summary, the ladder veins of Minnesota are barren quartz, mostly in magnetite-bearing pegmatite dikes, but one is known in granite and one in rhyolite porphyry. These rocks are such as might have developed shrinkage cracks on cooling; but the size of the openings is so great in proportion to the volume of the dikes as to make it somewhat doubtful whether cooling shrinkage explains all the open space. The hydrous nature of pegmatite magmas leads to a suggestion of some shrinkage by the escape of water. The common association of ladder veins and magnetite strongly suggests a connection between the nature of the pegmatite itself and the structure of the ladder vein, in contrast to any later development after the rocks were well established. The theory of differential movement of the walls, producing a tension in the formation, might easily explain the size of the openings, but does not readily explain their forms, and relation to the composition.

The ladder veins in pegmatites here described may be considered as a connecting link between those commonly described a occuring in igneous dikes and that in the vein of the Coeur

d'Alene district. The latter, as well as certain sedimentary formations in the gold fields of Victoria, have ladder veins so similar to the ladder veins of igneous dikes, that the definition of ladder veins should not be restricted to exclude them.

UNIVERSITY OF MINNESOTA,
MINNEAPOLIS, MINNESOTA.

DISCUSSION.

Mr. Lawson: I have observed some facts which may throw light on the origin of ladder veins. In the Keewatin of Rainy Lake there is a belt of strong rock about 100 feet wide, flanked on either side by weak rock, the dip being vertical. The weak rock has been rendered schistose by rock flow; and the same movement had the effect of sundering or pulling apart the massive strong rock. A series of cracks traverses the strong band irregularly transverse to its strike. These cracks are filled with quartz which has a fibrous structure, the fibers being normal to the walls of the cracks. The result is a series of ladder veins. The force that pulled the massive rock apart was the friction of the flowing rock on either side.

In the same region the well-rounded boulders of the Seine conglomerate have been pulled apart when the matrix in which they are imbedded was schistified. The boulders, ranging up to two feet in size, have been arranged with their longer axes parallel and pulled apart so that they are in discrete segments which are separated by one or several cracks varying in width from one eighth to one inch in width. These cracks are filled with fibrous quartz, the fibers being normal to the walls. The matrix in which the boulders lie is schistose.

In both these cases it is evident that the ladder veins are due to compressive stresses. The weaker portions of the formation have been caused to flow and the frictional grip of the flowing mass has been sufficient to sunder the stronger rock and develop in it a series of ladder veins.

These ladder veins may arise also in shear zones and carry valuable ores. In one mine that I examined some years ago in Alaska a shear zone some 200 hundred feet wide is characterized by many quartz veins carrying gold arranged in ladder fashion. The zone extended from the surface down into the mine for over 2,000 feet and the veins were disposed roughly parallel, but oblique to the zone. The whole zone was mined for its gold content.

A BENDIGO PROBLEM AND ITS BEARING ON FORCE OF CRYSTALLIZATION.

F. L. STILLWELL.

THE collected evidence and bibliography of Andrée[1] in 1912 on the pressure growth of crystals presents a body of opinion on its significance as a geological factor. The actual existence of forces associated with crystallization seems generally conceded in a limited manner under shallow or surface conditions or to growth in soft plastic sediments, such as clays. While Andrée considers the limiting power of these forces an important and undetermined question, he rather depreciates its far-reaching application by Lachmann for certain conditions in the North German salt deposits. Later writers, as Taber and myself, ascribe such power to this agent as would force apart the walls of deep-seated veins, sufficient to make room for the growing crystals, and it has been necessary to do this to reach any reasonable explanation of the phenomena under consideration.

The conception of fissure filling is, however, often maintained, either in the sense of the filling of gaping fissures or in the sense that earth movements conveniently open the fissure as it becomes gradually filled with vein material. To exponents of the fissure-filling theory the following Bendigo problem is presented as worthy of consideration, because the Bendigo saddle reefs have, until the last few years, been universally regarded as typical fissure deposits. It is also of interest to petrologists, for, if our interpretation is correct, the magnitude of the forces associated with the growth of crystals is such as to have an important bearing on the origin of structures and features arising through recrystallization in metamorphic rocks and through crystallization in igneous rocks.

[1] K. Andrée, "Die geologische Bedeutung des Wachsumdrucks kristallisierender Substanzen," *Geologische Rundschau*, 1912, 3, 7–15.

The Facts.—The facts of the present problem are represented in Fig. 69, which embodies typical features from geological mine

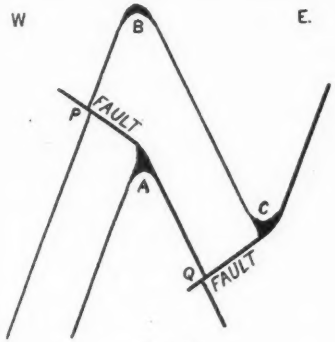

FIG. 69.

plans of Bendigo. A saddle reef, *A*, occurs at the intersection of an east dipping strike fault and the crest of the anticline. The quartz extends upwards for about distance along the fault, which, in its downward course, follows the east back of saddle reef *A*. In its upward course it intersects the west back or attenuated west leg of an overlying saddle reef *B*, and displaces it at *P* for distances averaging about 1 foot. At *P* the quartz in contact with the fault plane is slickensided and polished. Above *P* the quartz extends as a thin continuous sheet up its west leg to the saddle reef *B*, and then down the east leg or back as a thin sheet to the adjoining syncline, where it again enlarges into a trough reef *C*.

At *C* the relations of the fault to the reef is similar to that in the anticline at *A*, but inverted. A west dipping strike fault traversed down the east leg of the trough reef, forms the trough reef in the syncline, and then continues across the strata, intersecting the east leg of the saddle reef *A* at *Q*. The quartz on the fault plane at *Q* is slickensided and polished in the same manner as at *P*. Above *Q* the quartz extends as a thin continuous sheet up to the saddle reef *A*.

The Apparent Argument.—The saddle reef *A* is younger than the fault through *P*. The fault through *P* is younger than the west leg of the saddle reef *B* because it displaces and slickensides the quartz. The west leg is contemporaneous with the cap and therefore the saddle reef *A* is *younger* than the saddle reef *B*.

The saddle reef *B* is contemporaneous with the trough reef *C*. The trough reef *C* is younger than the fault through *Q*. The fault through *Q* is younger than the east leg of the saddle reef *A* because it displaces and slickensides the quartz. The east leg of the saddle reef *A* is contemporaneous with the cap and therefore the saddle reef *B* is *younger* than the saddle reef *A*.

The Problem.—The fallacy in this argument constitutes the problem. The reasoning only involves two inductions, one of which is applied at *A* and again at *C*, and the other which is applied at *P* and again at *Q*. Consequently one of the two inductions is incorrect.

The inductions at *A* and *C* can be supported in several ways. Not only does the quartz lie along the fault plane, but its occurrence is influenced by the fault. Its amount and its form is known to vary with variations of the fault.[2]

The second induction at *P* and at *Q* was first questioned on account of the distribution of gold. Gold which, on examination, was found to be as primary as any other constituent of the vein was frequently segregated around such intersections as *P* and *Q*. Yet the fault could exert no influence on the gold distribution if the fault were younger than the reef.

The induction at *P* and *Q* can be reversed on the view that the force of crystallization possesses sufficient energy to separate the bedding planes. A comparison of the artificial and natural veins renders this at least a reasonable view and the present circumstances seem to make it a necessary view. The manner of application is as follows:

[2] "The Factors influencing Gold Deposition in the Bendigo Goldfield," F. L. Stillwell. Comm. Adv. Counc. of Sci. and Indust., Bull. No. 4, p. 34; Bull. No. 8, p. 14; Bull. No. 16, p. 17.

"Gold Occurrences at Bendigo," F. L. Stillwell, *Proc. Aust. Inst. Min. and Met.*, n. s., no. 45, 1922, pp. 1–16.

In the first place, the strata are steeply folded. The later stages of folding involved the fracturing, faulting, and adjusting movements along the bedding planes. Faults and planes of movement guide the percolation of the solutions which give rise to the veins. At this stage we have Fig. 70, *A*, where the beds

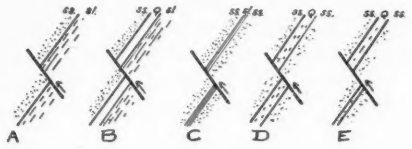

FIG. 70.

are displaced by a fault, and a plane of slipping is represented by a junction between a bed of sandstone and a bed of slate. Solutions may then percolate from the fault plane along this junction and, as deposition occurs, the crystals grow and make room for themselves. If the vein grows to a condition of Fig. 70, *B*, there are simultaneous adjusting movements along the fault plane, the plane of weakness. These adjusting movements are ample to account for the slickensided and polished quartz, which, otherwise, is most difficult to explain unless the fault is later than the reef—*i.e.*, unless the second induction of the apparent argument is correct. In Fig. 70, *B*, *C*, replacement and growth can be pictured together. The early percolation from the fault plane is supposed in Fig. 70, *C*, to replace a thin bed of slate, say, 3 inches wide. During replacement, and afterwards, the crystals may continue to grow so that the vein may expand as in Fig. 70, *D*, to a width of 12 inches or more. In this case the beds have been moved a distance of 9 inches, which is quite sufficient to polish and striate the quartz in the fault plane. If there is unequal percolation from the fault plane into the reef, the growth of the reef above and below the fault plane will be unequal, as indicated in Fig. 70, *E*.

The features embodied in these diagrams are known to depths of 4,000 feet at Bendigo. If the force of crystallization is suffi-

cient to produce adjusting movements in the beds, even at this depth its magnitude is enormous. There can be no doubt that were mining operations to penetrate much greater depths at Bendigo the same features would be reproduced. Further, their depth below the surface at the time of the formation of these veins, which are Devonian in age, was very much greater than their present depth. The inference, therefore, appears to be that the magnitude of these forces is of the same order as those forces which are spoken of as crustal forces in geological literature and which are involved in mountain-building movements.

BENDIGO,
AUSTRALIA.

EDITORIAL

CONGRESSIONAL INVESTIGATION.

CONGRESSIONAL investigations into any industry should be of more than academic interest to the country even though the conclusions founded on them are utilized only within the halls of congress, but when such investigations are used as a basis of propaganda broadcasted over the whole nation, then the way in which they are conducted and the conclusions reached by the committee become doubly vital, not only to the industry under examination but to the public at large. When the investigations have to do with industries based on economic geology, such, for instance, as the coal and oil industries, then it is time for the economic geologists to take a hand in the discussion.

Engineers, geologists and others with a scientific training, usually approach a problem with the idea of first securing all of the available data regarding it, and then after carefully digesting the evidence, draw conclusions which they believe are justified by the facts in hand. Conclusions reached by such a process should be fair and carry great weight.

Unfortunately, not all of those who reach a position of authority, enabling them to initiate and conduct important investigations into our industries, have had training and experience qualifying them to carry on systematic inquiries; and still more unfortunately, some of those who are clothed with such authority sometimes misuse their power for selfish reasons. Such persons do not try to discover the truth regarding the subject in question, but on the other hand endeavor to obtain so-called evidence supporting their pre-conceived and ofttimes dangerous ideas regarding the subject or, still more reprehensible, to obtain political capital with

which to fool the public and gain the support of such as do not think very deeply.

Investigations having these last two objects are usually conducted along the lines of adducing only such testimony as serves the selfish purposes of the instigators, ignoring, minimizing or refusing to consider opposing evidence, and finally winding up with an exaggerated prejudiced perversion which is flaunted before the public as the truth.

Broadly speaking, the difference between investigations undertaken by scientists and those carried on by politicians is that the scientist begins with facts and ends with a conclusion while the demagogue begins with a conclusion and ends with a fallacy.

Little harm would come from these travesties on a search for the truth were it not for the fact that the demagogues who conduct them are often prominent public officials in whom the unsuspecting public have reposed a certain degree of confidence.

The method of attack (and "attack" is here used advisedly) should disqualify most of these "investigations" before they are begun. They usually commence with a tirade by some self-seeking politician against an industry in which the public is deeply interested. This indictment is followed by a summoning of certain witnesses before an inquisitorial body, either a committee of the congress or of a legislature, when these interests are plied by questions obviously so worded as to bring out a biased conclusion. Evidence contradictory to the indictment is seldom admitted when offered by the witnesses. Irrelevant questions tending to prejudice the members of the "judicial body" are more often propounded than are questions which would tend to bring out the fundamental truths involved in the problem.

In most instances the investigating body and the chief inquisitors know little of the industry they are attacking, nor do they seem to want to know. They often have available, through the government or state bureaus, men perfectly familiar with the industry who, by intelligent questions, could bring out the fundamental facts relating to it. But such a logical procedure

is seldom indulged in—it might bring out facts fatal to the purpose of the inquisition.

I am not arguing against investigations properly carried out, neither am I holding a brief for industries which are conducted along lines inimical to the public welfare, but I do warn against the breeding of prejudice in the public mind against industries vital to our civilization and national welfare by the dissemination of false information and half-truths by demagogues who hope to profit thereby politically or otherwise. Such proceedings tend to cripple the industries under attack and may, if carried to the extreme, harmfully affect our national equilibrium.

The great majority of our legislators and officials, both national and state, are above the level of such actions, and I appeal to them to use their influence against the activities of their demagogue and muck-raking associates. Another antidote for these "investigations" is for each industry to furnish the public with the pertinent facts about itself so that the fallacies regarding its activities will fall on discriminating ears rather than on those of people ignorant of the real facts regarding the particular industry.

RALPH ARNOLD.

DISCUSSION AND INFORMAL COMMUNICATIONS

NOTE ON THE SOURCES OF ORIGIN OF CEYLON GEM-STONES.

Sir: Mr. Sydney H. Ball's very interesting paper on "The Geologic and Geographic Occurrence of Precious Stones" [1] raises the question (on page 593) of the sources of origin of the gem stones of Ceylon. The gem trade of that island is almost entirely in the hands of the so-called Moormen (an immigrant Tamil cast from south India professing Islam) and the Sinhalese gemmers. Neither the Sinhalese who win the gems nor the Moormen who purchase them at the diggings, or at auctions, concern themselves much about the origin of the stones, and among the former there are those who are content to accept by way of explanation a Persian legend, that seems to have been current for some centuries, attributing the invention of precious stones to the wiles of the devil who, by way of laying a foundation for much evil and temptation, created the gems in imitation of the flowers that Eve liked. A still older legend, and one which seems to meet with more favor, regards gems as the crystallized tears of gods who wept at the perversity and wilful wickedness of man. Most of the Moormen and some of the gemmers, however, believe that the stones grew in the gravels wherein they are found.

The selective destruction of mechanically unstable stones and the concentration of good material in gem placers is a natural process with which every economic geologist is familiar. As most are aware how extremely sparse is the distribution of the more valuable gems throughout the matrices that carry them, it

[1] ECONOMIC GEOLOGY, vol. XVII., No. 7, Nov., 1922.

will not be difficult to see why in Ceylon the placers have received so much attention while the possibilities of original sources have been almost entirely neglected.

Little is known of the parent rocks of any Ceylon gems, and with regard to the corundum varieties—the most important among the precious stones of the Island—some confusion seems to exist.

According to Dr. Herbert Smith [2] the Ceylon sapphire occurs with garnet in gneiss while ruby accompanies spinel in limestone. Goodchild,[3] on the other hand, remarks of the sapphires, "They are supposed to have been developed in the crystalline limestone of the district, but as yet have not been found *in situ*." Sir E. Tennant [4] states that rubies occur "in a stratum of dolomite at Bullatotte and Badulla," while Dr. Gygax, who examined the hill country to the south of Adam's Peak in 1847 for the purpose of reporting on the mineralogy of the district, declares that he found rubies of small size in "a stratum of gray granite associated with iron pyrites and molybdena at Hima Pohura about half way up the Eastern side of Pettigalle-Kande." Numerous other references of a similar character could be quoted, but, all considered, they create the strong impression of being founded on errors of diagnosis, and that the "rubies" seen *in situ* are in reality garnets or spinel, while some, at least, of the "sapphires" referred to are in reality blue apatite, a mineral that occurs characteristically in the crystalline dolomites and limestones of the metamorphic series. A study of the distribution of the illam (as the Sinhalese call the pay gravels) of the famous Ratnapura district, particularly of that along the Nireliela Ganga valley, leaves little room for doubt that the corundum gems, at any rate, are derived from pegmatites, and this conclusion is rendered all the more probable by the discovery made by the Principal Mineral Surveyor a few years ago of a sapphire-bearing pegmatite in the Muwara Eliya district, and

[2] "Gem Stones," London, 1912, page. 181.
[3] "Precious Stones," London, 1908, page 193.
[4] "Ceylon," London, 1860, vol. I., page 36.

of a discovery, on the part of some gemmers, of what appeared to be a similar occurrence near Matara.

Fairly large corundums *in situ* have been recorded from a few places but the crystals all display a prismatic habit and are opaque.

The sources of Ceylon gem stones appear on the whole to be most probably as follows:

Alexandrite—(see Chrysoberyl).
Andalusite—gneisses and schists.
Apatite—crystalline limestones (also occurs in large masses, but not as gem variety, in some graphite mines).
Beryl—(known in some mica veins) probably occurs in pegmatites.
Chrysoberyl—gneisses, schists and pegmatites.
Cordierite—gneisses and schists.
Diopside—crystalline limestones.
Garnet—gneisses and schists, Khondalites, granulites and pegmatites.
Moonstone—acid leptynite in the Kandy District and near Ambalangoda.
Ruby—probably in pegmatites or gneisses, or both.
Sapphire—pegmatites.
Sillimanite—gneisses and schists and Khondalites and corundum silimanite rocks.
Spinel—limestones and intrusive mica-spinel rocks.
Titanite—rocks of the Galle group, and pegmatites.
Topaz—granitic rocks and pegmatites.
Tourmaline—pegmatites.
Zircon—pegmatites (particularly those of the Balangoda group) and gneisses and schists.

E. J. Wayland.

Geological Survey of Uganda,
Entebbe, Uganda.

ORES OF THE SILVER ISLET MINE.

Sir: In his paper under the above title in the January number of Economic Geology, Mr. Chadbourn has some criticism to offer on the paper by Professor Parsons and the writer on "Animikite and Macfarlanite from Silver Islet, Thunder Bay,

Lake Superior," [1] with particular emphasis on the paragenesis of the ores as outlined in our paper. The writers of the above article, being both of them mineralogists, were more concerned with the elimination of two spurious mineral species than with the exact order of deposition of the various metallics. However, having committed himself as to the paragenetic relationships, the writer at least, after a careful perusal of Mr. Chadbourn's paper, finds himself still unconvinced as to the correctness of the latter's interpretation of the paragenesis. The writer contends that, even from Mr. Chadbourn's illustration *B* of Plate IV., it might equally well be inferred that the silver formed first and the niccolite afterwards, the latter forcing itself in between the silver and the galena. There can, of course, be no doubt that the galena formed before either of these two minerals. As to the form in which the antimony appears in the ores, the writer is inclined to agree with Mr. Chadbourn that dyscrasite is the mineral in question rather than breithauptite although the molecular proportions of nickel and antimony would agree better with the latter mineral. The nickel antimonide is so easy of identification that it could hardly be passed over even in small quantities. In this connection it is interesting to note that most so-called dyscrasite is in reality a eutectic mixture of native silver and a silver antimonide, the latter probably corresponding to the formula Ag_3Sb [2]. As to the resemblance these ores bear to those of the Cobalt district, the writer would point out that the paragenesis of the Silver Islet ores is complicated by the presence of considerable quantities of galena and sphalerite, neither of which minerals occur in any quantity at Cobalt.

ELLIS THOMSON.

[1] Parsons, A. L. and Thomson, E., Univ. of Toronto Studies, Geol. Series, No. 12, pp. 23–26.

[2] Walker, T. L., University of Toronto Studies, Geological Series. No. 12, pp. 20–22.

REVIEWS

Mercury Ores. By EDWARD HALSE. Imperial Institute monographs on mineral resources, with special reference to the British Empire. John Murray, London, 1923. Price, 5 shillings.

The monograph on mercury ores, like others in this series, is a compact general summary of knowledge concerning the ores of a particular metal. It is exceptionally well done and probably nowhere else is there gathered together so much up-to-date information concerning the scattered quicksilver deposits of the world. The material relating to the deposits of the British Empire, not any of which are at present of much economic importance, has been very carefully compiled from many sources. The treatment of the American deposits, while necessarily brief, is generally accurate, and the compilation has been made with skill and discrimination. There are a few minor errors in proper names and geographical position, and some of the statements of Becker concerning the California deposits would probably not have been accepted by an investigator familiar with that field. But as a whole the volume is an excellent piece of work and should be of value to all who are interested in the occurrence and distribution of quicksilver.

F. L. RANSOME.

Maps. Their History, Characteristics, and Uses. A Handbook for Teachers. By SIR H. G. FORDHAM. Cloth, 83 pages, 5½x8, and VIII. plates. The University Press, Cambridge, 1921.

The text contains the substance of five lectures embodying the history of map-production from the earliest times, from the point of view of science and practice and of "the continuous development of the graphic art as applied to the pictorial and the technical representation of sections of the earth's surface on paper." The author believes that a proper appreciation of the importance of maps is best gained by a study of the slow development of map-making. He carries the reader through the various steps by which the modern map was approached, from the time of Eratosthenes of Cyrene (276–196 B.C.) to the present day. He de-

scribes the different types of maps, discusses briefly the art of drawing and producing them, and gives some suggestions as to the methods by which young students may be made to take interest in them. Eight plates of famous maps illustrate the author's points. The book is interestingly written. It contains a great deal of material in a very small space.

W. S. Bayley.

SOCIETY OF ECONOMIC GEOLOGISTS

This department has been established for the official communications of the Society of Economic Geologists whereby the affairs of the Society such as notices, minutes, titles of papers, elections, etc., may be brought regularly to the attention of its members.

Below is a cut of the Penrose Medal of the Society of Economic Geologists, which is to be presented not oftener than once in three years to geologists, whether members of the Society or not, making important contributions to the earth sciences. (Actual size of medal 4⅛" x 2¾".)

From funds received as royalties on the sales of the volume POLITICAL AND COMMERCIAL GEOLOGY edited by J. E. Spurr, the Society presented a scholarship in political and commercial geology during the collegiate year 1922–23. Further funds accumulated from the same source make it possible to offer a scholarship for the collegiate year 1923–24.

Applications for the above fund, giving qualifications, should be sent to the Chairman of the Committee on Royalties, Mr. E. C. Harder, 1111 Harrison Building, Philadelphia, Pa.

SCIENTIFIC NOTES AND NEWS

Frederick Leslie Ransome, of the U. S. Geological Survey, has accepted an appointment as professor of geology and head of the department at the University of Arionza, Tucson, Arizona, for the coming academic year. Dr. Ransome has not severed his connection with the Geological Survey and may not decide to remain permanently in Arizona.

Waldemar Lindgren, assisted by Henry C. Boydell, is making a geological investigation of the Eureka mining district of the U. S. Smelting, Refining and Mining Co.

J. A. Bancroft, of McGill University, is spending the summer at Anyox in an endeavor to extend the Granby Company's ore bodies.

Adolph Knopf, of Yale University, is in Aspen, Colorado, for the U. S. Geological Survey.

Cyril W. Knight, Assistant Provincial Geologist of Ontario, is resigning his position with the Department of Mines to enter the service of the Nipissing Mining Co.

Guy N. Bjorge is doing professional work at Globe, Arizona.

Arthur L. Walker, of Columbia University, is in South America visiting the principal mining properties, and will sail later for Spain, Portugal, Italy, and Cairo.

B. Rose, of Queens University, and A. G. Burrows, of the Ontario Department of Mines, have been making an investigation of the Porcupine gold area.

H. Foster Bain and H. S. Mulliken, of the Bureau of Mines, are in South America investigating the Chilean nitrate situation.

Francis Drake has left England for Uruguay.

R. J. Garnes has accepted a position as Petroleum Geologist with the Petroleum Exploration at Lexington, Kentucky, to examine oil property in Kentucky and adjoining States.

Oliver Bowles, mineral Technologist of the Bureau of Mines, has been designated by the Secretary of the Interior as superintendent of the mining experiment station to be established at Rutgers College, New Brunswick, N. J., which will specialize in problems involved in the production and utilization of the various non-metallic minerals.

Reno H. Sales was elected Chairman of the Montana Section of the American Institute of Mining and Metallurgical Engineers.

W. J. Miller is conducting an aerial survey of the crystalline rocks of the Adirondacks, in the Thirteenth Lake region, for the New York Geological Survey.

Victor Dolmage, head of the British Columbia branch of the Geological Survey of Canada, is making a geological survey of Copper Mountain.

Olaf P. Jenkins, associate professor of economic geology, State College of Washington, is making a geological examination of the coals of Skagit County, Washington, for the Division of Geology, Department of Conservation and Development. This is a continuation of the work he did in Whatcom County last summer, the report of which is now in the hands of the State Printer.

The Oklahoma Geological Survey is without funds for the next two years, owing to the action of the Governor. C. W. Shannon, the State Geologist, F. M. Bullard, and Bess U. Mills have resigned and opened a bureau of geology at Norman. Dr. C. E. Decker, associate professor of geology at Oklahoma University, has been appointed custodian of the records of the Geological Survey. Bulletin 32 of the Survey entitled: "Geology of the Southern Washita Mountains of Oklahoma," by C. W. Honess, is being published and will be available at a later date for distribution through Dr. Decker.

On June 3, a bronze tablet, presented by the Geological Department of the University of Wisconsin, was installed on "Van Hise rock" in the Baraboo district of Wisconsin. This rock illustrates important principles of structural geology, and has been widely used in textbook illustrations. Addresses were given by C. K. Leith and W. H. Twenhofel, of the University of Wisconsin.

We regret to learn of the death on June 11th, of Joseph Keele, a member of the staff of the Geological Survey of Canada. Mr. Keele spent the earlier years of his connection with the Survey in making geological explorations in Yukon and Northwest Territories. He is better known for his work on clays and shales of Canada in their application to the ceramic industries.

The West Virginia Geological Survey, Morgantown, West Virginia, announces the publication of a detailed report on Tucker County, by David B. Reger, accompanied by a separate case of topographic and geologic maps. The price is $3.00, delivery charges prepaid.